United States
Department of
Agriculture

Forest Service

Northeastern Forest Experiment Station

General Technical
Report NE-148

PROCEEDINGS

8th Central Hardwood Forest Conference

University Park, Pennsylvania
March 4-6, 1991

For attending this conference, each registrant was eligible for 12 hours of Continuing Forestry Education (CFE) credit offered by the Society of American Foresters.

ACKNOWLEDGEMENTS

The editors would like to acknowledge and thank all of the people who served as manuscript reviewers for the Proceedings. The quality of the Proceedings has been improved due to your efforts. We would also like to thank Dr. Mark J. Twery, David E. Fosbroke, Shirley I. Smith, and Mark A. Mitchell for their assistance in converting wordprocessing documents, proofreading, preparation of the table of contents, and layout assistance and Arlyn W. Perkey for providing the cover photograph.

Northeastern Forest Experiment Station
5 Radnor Corporate Center
100 Matsonford Road, Suite 200
P.O. Box 6775
Radnor, Pennsylvania 19087

March 1991

8TH CENTRAL HARDWOOD FOREST CONFERENCE

Proceedings of a Meeting

Held at

The Pennsylvania State University

University Park, PA

March 3-6, 1991

Edited by

Larry H. McCormick and Kurt W. Gottschalk

SPONSORED BY:

School of Forest Resources, Pennsylvania State University

Northeastern Forest Experiment Station, USDA Forest Service

Bureau of Forestry, Pennsylvania Department of Environmental Resources

in cooperation with the Office of Conferences and Short Courses, College of Agriculture, Pennsylvania State University.

PROGRAM COMMITTEE

Co-chairs:

Kim C. Steiner (program), Larry H. McCormick (proceedings), Todd W. Bowersox (arrangements), School of Forest Resources, Pennsylvania State University.

Committee Members:

Kurt W. Gottschalk and Stephen B. Horsley, Northeastern Forest Experiment Station, USDA Forest Service, and Glen R. Stanosz, Bureau of Forestry, Pennsylvania Department of Environmental Resources.

FOREWORD

This conference is the eighth in a series of biennial meetings that began in 1976 at Southern Illinois University. Other conferences have been hosted by Purdue University, University of Missouri, University of Kentucky, University of Illinois, and University of Tennessee. The purpose of these conferences has remained the same: to provide a forum for the exchange of information concerning the central hardwoods and to engender coordination among forest scientists in the central hardwood region. This purpose is evidently well-served: the last several conferences have each attracted some 45 to 65 program contributions, and the audiences have been correspondingly large.

Previous organizers have refrained from drawing precise boundaries around the "central hardwood region." We prefer to continue that policy on the grounds that to do otherwise might preclude some very worthwhile participation. Thus, while the principal focus has remained on the oak resource for reasons that are obvious, the ecological scope has broadened from oak-hickory (in the early meetings) to Appalachian oak (Knoxville and State College) and mesophytic forests. With a few exceptions, the commercially significant species are similar for all these forest types, and advancements in knowledge are of general interest.

But the central hardwood region is not merely a collection of similar forest types. It also has historical, demographic, political, and economic characteristics that tend to distinguish it from other forest regions of the United States. For example, the population is heavily rural and agricultural, primary wood markets tend to be diffuse and unorganized, wilderness values and endangered species have generally not been overriding issues, and a relatively minor proportion of the forest land is controlled by public agencies or corporate ownerships. These and related conditions play critical roles in the practice of forestry in this region, and in the aggregate they emphasize its distinction from other regions; but no single one is necessarily unique to the central hardwoods. For these reasons, the characteristics of nonindustrial private forest land owners in Massachusetts might be just as relevant to the central hardwood region as regeneration methods for white oak in Indiana.

Since these proceedings are being published in advance, we have no way of judging the ultimate success of the upcoming Eighth Conference. Of course, our earnest hope is that this meeting shall sustain the excellent reputation of the series. We believe this hope is encouraged by the quality of the papers in these proceedings.

REVIEW PROCEDURES

Each manuscript published in these proceedings was critically reviewed by at least two scientists with expertise in disciplines closely aligned to the subject of the manuscript. Reviews were returned to the senior author, who revised the manuscript appropriately and resubmitted it in a diskette format suitable for printing by the Northeastern Forest Experiment Station, USDA Forest Service where they were edited to a uniform format and type style. Manuscript authors are responsible for the accuracy and style of their papers.

TABLE OF CONTENTS

POSTER SESSION

INSECTS AFFECTING ESTABLISHMENT OF NORTHERN RED OAK SEEDLINGS IN CENTRAL PENNSYLVANIA

Jimmy Galford, L. R. Auchmoody, H. Clay Smith, and Russell S. Walters[1]

Abstract: Studies to evaluate the impact of insects on the establishment of advance oak regeneration in Pennsylvania were initiated in 1989. The populations and species of insects feeding on germinating acorns and new seedlings, their activity periods, and the damage caused by these insects were studied in relation to overstory-density (40, 60, and 100 percent relative density) and understory vegetation control (herbicided and unherbicided) at three sites on the unglaciated Allegheny Plateau in Clearfield County. These experiments showed that overstory-density levels and treatment with herbicide to eliminate the understory had negligible effects on the species of acorn-feeding insects present, their population levels, and their damage to germinating red oak acorns and new seedlings. These experiments also showed that acorn weevils (*Conotrachelus posticatus* (Boheman), nitidulids (*Stelidota octomaculata* (Say), and acorn moths (*Valentinia glandulella* (Riley) are important acorn predators, that they become active during late winter and spring, and that they destroy great numbers of germinating acorns and new seedlings in central Pennsylvania oak stands, thus affecting oak regeneration.

INTRODUCTION

"Although there seems to be a universal problem with regenerating northern red oak, there is not a universal solution. Specific requirements for local conditions will need to be developed from the general requirements for regenerating the species". These comments by Crow (1988) are supported by the large volume of literature on the problem of regenerating oak, yet this problem remains a formidable one.

One problem that is encountered in regenerating mature oak stands on good and excellent growing sites can be traced to a lack of advance oak reproduction. The oak seedlings must be of sufficient size to successfully compete with other faster growing species when the stand is regenerated (Sander 1988; Loftis 1988; Lorimer 1989).

---

[1]Research Entomologist, U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station (USDA-FS, NEFES), Parsons, WV 26287, Research Forester, USDA-FS, NEFES, Warren, PA 16365, Research Forester/Project Leader, USDA-FS, NEFES, Parsons, WV 26287, and Research Forester, USDA-FS, NEFES, Warren, PA 16365, respectively.

In 1988, the Northeastern Forest Experiment Station initiated a series of studies to identify and understand the important factors that limit the development of advance red oak reproduction on high-quality growing sites in Pennsylvania, West Virginia, Ohio, and Kentucky[2]. The effects of deer, rodents, insects, light, competition from herbaceous and woody species, site, stand composition, and acorn availability are some of the factors being evaluated.

The first research plots were established in 1988-89 on the Moshannon State Forest in central Pennsylvania. This paper reports early results from studies on the impact of insects on the establishment of northern red oak (*Quercus rubra* L.) seedlings.

DESCRIPTION OF STUDY AREA

The Moshannon State Forest is located in four counties in central Pennsylvania within the unglaciated Allegheny Plateau region. The experiments were conducted in the Clearfield County section of the Forest, where the elevation is about 2200 feet. Precipitation averages 45 inches and is distributed uniformly throughout the year. The area is usually snow covered from December through mid-March. Soil moisture is usually ample during the spring and early summer, though intermittent periods of moisture stress are common during the latter part of the growing season. The frost-free period is about 130 days.

All of the study stands originated after a complete clearcutting shortly after the turn of the century. As a result, they are even-aged and about 80+ years old. The site index for northern red oak is about 70.

Following clearcutting, many factors, including repeated fires, gave rise to the fully stocked, second-growth hardwood stands that are present today. These stands have a major component of northern red oak growing in mixture with black cherry (*Prunus serotina* Ehrh.), sugar maple (*Acer saccharum* Marsh.), red maple (*Acer rubrum* L.), and white ash (*Fraxinus americana* L.). Other species represented include yellow-poplar (*Liriodendron tulipifera* L.), American beech (*Fagus grandifolia* Ehrh.), cucumbertree (*Magnolia acuminata* L.), bigtooth aspen (*Populus grandidentata* Michx.), hickory (*Carya* spp.), white oak (*Quercus alba* L.), black oak (*Quercus velutina* Lam.), and chestnut oak (*Quercus prinus* L.).

The understory on the study areas is limited in abundance and diversity, reflecting long-term browsing from the high deer population that numbers between 31 to 34 per square mile

---

[2]Study Plan: Factors limiting the establishment of advance oak regeneration in mature oak stands by H. Clay Smith and L. R. Auchmoody (called Limiting Factors Study).

(Powell and Considine 1982; Pennsylvania Game Commission)[3]. Hay-scented fern (*Dennstaedtia punctilobula* L.), New York fern (*Thelypteris noveboracencis* L.), striped maple (*Acer pensylvanicum* L.), and American beech are not preferred by deer and, therefore, are the species found most frequently in the understories. Desirable hardwood regeneration also is sparse, being limited to species that are low in preference as deer browse. Virtually all oak seedling regeneration is less than 15 inches tall due to repeated browsing. The number of advance red oak seedlings ranges from about 60 to 350 per acre.

METHODS

The field design of the Clearfield installation on the Moshannon State Forest consists of six, 4-acre cutting-level plots arranged in three randomized complete blocks (a total of 18 plots). Treatments applied to these plots were: 1) three cutting levels (40, 60, and 100 percent residual relative density); 2) fencing half of the plots to exclude deer; and 3) herbicide (glyphosate) applied to one-half of each of the 18 plots to eliminate the understory vegetation. Each block (replicate) was located in a fully stocked stand in which northern red oak was a principal component, and that also was representative of the oak stands in the area. Herbicide was applied in August 1988, and the overstory treatments were made in the winter and spring of 1989.

Studies to determine the relative populations and species of insects that might be causing damage to red oak acorns were conducted in the spring of 1989 and 1990. Both experiments used pitfall traps to catch the insects. The pitfall traps consisted of pint canning jars with 10-ounce plastic cup inserts containing a paper towel, 20 ml of water, and four or five viable red oak acorns that had been cut into halves (bait). The jar sealing caps were replaced with 1/4-inch hardware cloth circles to allow entry by the insects. The wire discs were glued inside the screw caps with epoxy ribbon adhesive to prevent rodents from pulling out the wire screens. The traps were buried in the soil with the tops flush with the ground. Rain shields for the traps were provided by positioning plastic food container lids (6- to 8-inch diameter), supported on 10-inch nails, about 3 inches above the tops of the traps. The traps were checked at 7- to 10-day periods. At the end of each trapping period, the insects that were caught were identified and counted, and the traps equipped with new plastic cup inserts containing fresh acorn bait.

In 1989, the trapping period was between May 3 to June 13 and a total of five collections were made. That year, 4 pitfall traps (2 in each herbicided and unherbicided section of each cutting level) were placed in each of the 6 plots at replicates 2 and 3 and also in the two uncut (100 percent relative density) plots of replicate 1, a total of 56 traps. The 40 percent and 60 percent relative density plots at replicate 1 were not trapped in 1989 because rain

[3]Unpublished Pennsylvania Game Commission annual estimate of winter deer population estimates by William Palmer.

delayed the completion of the cutting treatments until mid-June. In 1990, the trapping period was between May 15 and June 6 and a total of three collections were made. During 1990, two pitfall traps were placed in each herbicided and unherbicided section of all plots, for a total of 72 traps. Analysis of variance was used to determine if the insect species present or their population levels were affected by the residual stand densities on the plots and by the application of herbicide (i.e. understory removal).

In separate experiments to evaluate insect damage to germinating red oak acorns and young seedlings, direct-seeded acorns were used along with 6-inch-square, open-bottom wire boxes of 0.5- by 1.0-inch hardware cloth to protect sown acorns from chipmunks and larger mammals. The wire boxes were secured to the ground with 12-inch landscaping nails or 8-inch plastic tent stakes. As with the pitfall trap experiments, these studies also were conducted in the herbicided and unherbicided sections of the main cutting-level plots (40, 60, 100 percent relative density).

The first of the experiments began in early May 1989 and was conducted on seven plots where deer were excluded and one unfenced plot. Six wire boxes were placed in herbicided and unherbicided sections of each plot. Under each wire box, two red oak acorns were planted 1-inch deep and two acorns were placed on the soil surface. At a distance of 1 foot from each of 2 sides of the wire box, one acorn was planted 1-inch deep and one placed on the soil surface (eight acorns total per site). All acorns inside and outside the boxes were covered with leaves. The acorns, which had been collected in 1988 and kept in cold storage, were just beginning to germinate so all were viable when sown. Thus, 768 acorns were deployed; half were protected from rodents and half were surface or subsurface sown. The sites were checked in late June to determine the extent of insect and rodent damage. Differences in damage attributed to residual overstory density and to understory removed by herbicide were determined by analysis of variance (ANOVA).

The second experiment began in late October and early November of 1989. Ten wire boxes were placed in each herbicided and unherbicided section of all 18 plots. Under each wire box, five red oak acorns were placed on top of the ground and covered with leaves. The boxes were secured to the ground with 12-inch landscaping nails or 8-inch plastic tent stakes. The acorns used in this study were collected outside of the study plot boundaries and float-tested; any acorns showing signs of insect or other damage were discarded. The boxes were distributed throughout the plots and placed under acorn-bearing trees. Thus, 100 acorns were sown in each cutting-level plot (1,800 acorns total). The wire boxes were lifted and the acorns and seedlings checked for damage in May, June, and July of 1990. The heights of the seedlings were measured in July when the boxes were removed from the plots. Differences in damage between the residual overstory densities and from the removal of the understory with herbicide were evaluated by ANOVA.

The viability of the acorn crop and effects of insects thereon were determined from acorn samples taken in November inside 14- by 42-ft. fenced rodent-exclosure plots inside the fenced 4-acre plots (Auchmoody et al. - unpublished). This eliminated variation due to removal of acorns by rodents prior to sampling. A sample of 10 to 25 acorns was collected in each rodent-exclosure plot. The acorns were packed in moist peat moss in plastic bags and stored at 45 to 50°C. Several small holes were punched in each bag to allow aeration. About 3 months later the bags were placed at room temperature and a small amount of water was added to each bag. After 2 weeks the acorns were checked for germination. Inviable acorns were cut open and inspected to determine the cause of germination failure.

A final study was conducted to determine when feeding activity by acorn insects begins. A sample of 300 acorns was collected near the plots on February 13, 1990, and a second sample of 235 acorns was collected on March 15, 1990. The acorns were examined in the laboratory and insect activity associated with each of the sampling dates was determined.

RESULTS

Three important species of insects that damage germinating acorns were caught in the pitfall traps in 1989 and 1990: the weevil, *Conotrachelus posticatus* (Boheman); the nitidulid or sap beetle *Stelidota octomaculata* (Say); and the acorn moth, *Valentinia glandulella* (Riley). Table 1 gives the mean number of weevils and sap beetles caught per trap per trapping period for five periods in 1989 and three periods in 1990.

Analysis of variance revealed no significant differences in weevil or sap beetle populations associated with the overstory-density treatments or with the removal of the understory with herbicide in either years. Thus the data from all plots within a replicate were pooled and the replicate means were analyzed for differences. The weevil population in both 1989 and 1990 was significantly lower in Replicate 1 than in Replicate 2 but not significantly lower than in Replicate 3. The Replicate 2 and Replicate 3 plots did not differ significantly in 1989 but they did in 1990.

Table 1.--Mean number of weevils, *Conotrachelus posticatus*, and sap beetles, *Stelidota octomaculata*, caught per pitfall trap per trap period, 1989 and 1990[a]

Area	Weevil		Sap Beetles	
	1989	1990	1989	1990
Replicate 1	4.8 a[b]	0.3 a	0.9 a	0.1 a
Replicate 2	8.2 b	0.8 b	7.9 b	2.4 b
Replicate 3	6.2 ab	0.3 a	10.0 b	1.9 b

[a]Mean shown for each replicate is the mean of pooled plot data since ANOVA showed no significant differences in either insect population due to different overstory densities or to removal of understories with herbicide in either year.
[b]Means in the same column followed by the same letter are not significantly different at the 95 percent level.

Populations of sap beetles in Replicate 1 were significantly lower in both 1989 and 1990 than in Replicates 2 and 3. There was no significant difference in sap beetle populations between Replicates 2 and 3 in either years.

Populations of the acorn moth *V. glandulella* were not determined from pitfall traps in 1989 or 1990, but many moths were reared from the acorns used as bait in the pitfalls. However, because this insect was thought to be a minor acorn pest, no attempt was made to monitor exact numbers. Subsequently, germinating acorn samples collected on March 15, 1990, near the study plots revealed that the radicle tips of 50 percent of the acorns had been eaten by the moth larvae and laboratory rearing showed that 60 percent of the acorns were infested with moth larvae. As a result, this insect must now be considered a major pest of germinating acorns in Pennsylvania, and future studies should monitor the populations of *V. glandulella.*

Table 2 presents the 1989 results of subsurface- and surface-sown acorns inside and outside of hardware-cloth boxes. There were 192 acorns in each of the four treatments. Analysis revealed no differences due to overstory density, herbicide treatment, or plot location (replication) so the data given in Table 2 is the pooled data from all plots. Acorn placement and rodent protection did result in significant differences in numbers of seedlings, acorns taken by rodents, and acorns destroyed by insects. Rodents destroyed virtually every acorn outside of the boxes -- all of the acorns on the surface and 150 (78 percent) of those buried. Under the boxes, insects destroyed 177 (92 percent) of the acorns on the surface but only 16 (8 percent) of those buried. One hundred and seventy-six (92 percent) of the acorns buried under a wire cage produced a seedling while only 41 (21 percent) of those buried without protection from rodents produced seedlings. Seventeen of the subsurface acorns were destroyed by weevils and sap beetles which enter loose soil to feed on acorns.

Table 2.--Results of 1989 test in which 192 acorns per treatment were surface or subsurface sown, inside or outside of wire boxes -- number of acorns lost to rodents and insects and seedlings produced.*

Treatment	Seedlings	Acorns taken by rodents	Acorns destroyed by insects
		---number---	
A - Surface-inside	15	0	177
B - Surface-outside	0	192	0
C - Subsurface-inside	176	0	16
D - Subsurface-outside	41	150	1

*Data pooled for all study areas. T-test showed no significant differences in number of seedlings relative to overstory density, herbicide treatment, or study area. Surface treatment (A) inside and subsurface treatments (C and D) inside and outside boxes significantly increased seedling establishment ($P \leq 0.05$).

As shown in Table 3, insects destroyed 87 percent of the germinating acorns and new seedlings that resulted from 1,800 acorns placed under the wire boxes in autumn of 1989. Insects destroyed 270 (64 percent) of the 422 seedlings that established from 1139 germinating acorns. Only 152 (13 percent) of the 1,139 germinating acorns and seedlings survived insect destruction and 113 of the seedlings were in Replicate 1. The insect damage listed in Table 3 is based only on acorns that germinated since rodents destroyed some of the acorns and nonviable acorns were not subject to insect damage. The insect damage was primarily by the acorn moth and the *Conotrachelus* weevil. Laboratory rearing of the acorns removed from the wire boxes revealed that at least one-third were infested with moths and nearly all with weevils. Most of the newly rooted seedlings were killed due to heavy weevil feeding on the radicles and shoots. There also was some damage to newly rooted seedlings by *S. octomaculata* in concert with the weevils. The sap beetles ate the tender top-shoots as they formed and reproduced in the acorn cotyledons, destroying any chance for the acorn to resprout and form a seedling.

Table 3.--Fate of 1800 northern red oak acorns surface-sown under wire boxes in autumn of 1989 and checked May, June, and July 1990.[a]

	Replicate			Total	Percent
	1	2	3		
	-----Number-----				
A - Germinating acorns destroyed by insects	242	265	210	717	63*
B - Seedlings destroyed by insects	92	129	49	270	64*
A + B - Total number of acorns and seedlings destroyed by insects	334	394	259	987	87*
Surviving seedlings	113**	26	13	152	13

[a]Of the 1,800 surface sown acorns, 661 (37 percent) failed to germinate because of mouse predation (7 percent) and desiccation (30 percent). Plot data pooled for each replicate since ANOVA showed no significant differences within a replicate relative to overstory density or understory control.
*Percentages based on 1,139 acorns that germinated and 422 seedlings that initially established from the 1,139 acorns.
**Significantly different at 99 percent level from Replicates 2 and 3.

The acorn samples removed in November 1989, from the rodent-exclosure plots revealed that 132 of 536 (24.7 percent) were infested with insects, primarily *Curculio* sp. larvae. Less than 2 percent of the acorns were infested with the filbertworm moth, *Cydia latiferreana* (Wlsm.) and the acorn moth, *V. glandulella*. Surprisingly, larvae of *V. glandulella* were found in sound, previously undamaged acorns, having gained entry into the acorn by chewing through the micropyles on the cap end of the acorn. This is the first report of this insect being a primary invader of sound, ungerminated acorns. It is believed that the larvae are able to chew only into immature acorns. Damage to the cotyledons was confined to the cap ends and had no affect on acorn viability. Sixty-two (47 percent) of the acorns infested with *Curculio* weevils and *Cydia* moths failed to germinate while 70 (53 percent) germinated. Ideal germination conditions in the laboratory probably allowed many insect infested acorns to produce seedlings that otherwise would have desiccated under natural conditions. However, at least 12 percent of the 1989 bumper acorn crop was not viable due to insect damage.

The samples of germinating acorns collected on February 13, 1990, revealed that the acorn moth, which overwinters as an early instar larva, had just begun to feed. In this sample, only 13 of 300 acorn radicles had been damaged, but by March 15 the radicles of 118 of the 235 acorns collected had been damaged by moth larvae. Weevil damage was not observed in the February sample of acorns and by March 15 weevil feeding and oviposition had just begun. Activity by sap beetles was not detected in either of the acorn samples. Adult sap beetles were found on moth- and weevil-destroyed acorns under the wire boxes on May 7, 1990. However, sap beetle reproduction was not detected until a second check of the acorns under the boxes on June 7 revealed that reproduction probably began in late May.

DISCUSSION

The average number of weevils and sap beetles caught in the pitfall traps in 1990 appears very low compared to 1989 (Table 1). In 1990, the traps were competing with a large number of residual acorns from the 1989 bumper crop. By contrast, in 1989, wildlife had consumed nearly all of the acorn crop by June, which resulted in greater numbers of insects being attracted to the traps. Insects destroyed 987 (87 percent) of the 1,139 germinating acorns and young seedlings under the wire boxes in 1990 (Table 3). This indicates that the acorn-insect population actually was very high in 1990. Thus, the number of acorn insects trapped in pitfalls must be evaluated over time in relation to acorn food sources available in the surrounding area to accurately assess populations.

The pitfall trapping period was shorter in 1990 than in 1989 but was conducted during the ideal time for assessment of weevil and sap beetle populations that overwintered within the plots; when temperatures were below the threshold for flight of the acorn insects but high enough for the insects to readily migrate to the traps by walking. The overwintering populations of acorn insects are the most damaging and their populations within an area are best assessed before migration or emigration by flight can occur and before emergence of new adults occurs in late spring and early summer.

Mice destroyed 119 (7 percent) of the 1,800 acorns placed under the wire boxes. However, 95 acorns were eaten by mice in just two plots in Replicate 3. This demonstrates the localized effect of some species of rodents on seedling establishment. The hardware-cloth mesh allowed entry by mice. Mice usually eat off the cap ends of the acorns, leaving a nearly intact acorn hull; other rodents typically leave the acorn hull in pieces.

Of the 152 new seedlings that were established under the wire boxes in 1990, only 51 were undamaged by rodents. Rodents chewed off the tops of most seedlings emerging from the wire boxes. This type of rodent damage also was observed in Ohio (Galford et al. 1988). Seedlings not damaged by rodents ranged in height from 1 to 12 cm and averaged 5.4 cm. The smallest seedlings resulted from acorns heavily damaged by insects; none appeared vigorous.

Snowfall was less than normal during the winter of 1989-90 in the study area, and rainfall was below normal in March and April of 1990. This may account in part for the large number of acorns (30 percent) that did not germinate. Laboratory germination tests of samples of the acorns used in the study showed that 97 percent were viable. The dry conditions at the time of acorn germination also may have influenced the impact of insects on seedling establishment. Delayed acorn germination and a slow rate of radicle growth due to a moisture deficit would expose the radicle tips to insect feeding for a longer period.

The low population of sap beetles in the Replicate 1 plots (Table 1) may have been a factor in a greater number of seedlings being established under the wire boxes in 1990 (Table 3). However, the importance of the sap beetles is not completely known. Additional studies are needed to establish insect and rodent population interrelationships with respect to acorn abundance and seedling establishment.

Examination of several hundred newly established red oak seedlings in and near the plots in 1989 revealed that only two seedlings originated from surface acorns. Nearly all of the seedlings establishing in areas undisturbed by the logging operations resulted from acorns buried or otherwise cached by rodents. By contrast, in 1990 more than 70 percent of the new oak seedlings that were examined originated from surface acorns under leaf litter. Thus, the large acorn crop of 1989 allowed some unburied acorns to survive predation by both insects and rodents.

Data obtained on insect species that feed on germinating acorns and their impact on seedling establishment in central Pennsylvania parallels results from studies on acorn insects in Ohio (Galford et al. 1988).

In conclusion, insects and rodents singly or in combination can significantly limit the number of oak seedlings establishing in central Pennsylvania forests, even in years of large acorn crops. Foresters have long known that logging operations following a good acorn crop can increase oak seedling establishment. Many acorns are covered or pressed into the soil during logging. The results of this study demonstrate that buried acorns are afforded protection from insect and rodent predation and desiccation, which increases oak seedling establishment.

AKNOWLEDGEMENTS

We gratefully acknowledge forestry personnel with the Pennsylvania Department of Environmental Resources for their help and cooperation in establishing the research plots.

We also thank technicians Perry Fox and Dave Saf and other NEFES scientists and technicians for their efforts and cooperation.

LITERATURE CITED

Crow, T. R. 1988. Reproduction mode and mechanisms for self-replacement of northern red oak (*Quercus rubra*)---a review. For. Sci. 34:19-40.

Galford, J. R., J. W. Peacock, and S. L. Wright. 1988. Insects and other pests affecting oak regeneration. In: Smith, H. C., A. W. Perkey, and W. E. Kidd, Jr., eds. Guidelines for regenerating Appalachian hardwood stands: workshop proceedings. May 24-26, 1988. SAF Publ. 88-03. West Virginia University Books. p. 219-225.

Loftis, D. L. 1988. Regenerating oak on high-quality sites, an update. In: Smith, H. C., A. W. Perkey, and W. E. Kidd, Jr., eds. Guidelines for regenerating Appalachian hardwood stands: workshop proceedings. May 24-26, 1988. SAF Publ. 88-03. West Virginia University Books. p. 199-209.

Lorimer, C. G. 1989. The oak regeneration problem: new evidence on causes and possible solutions. Univ. Wisconsin Dep. For., For. Resour. Anal. No. 8. 31 p.

Powell, D. S. and T. J. Considine, Jr. 1982. An analysis of Pennsylvania's forest resources. USDA For. Serv. Resour. Bull. NE-69. 97 p.

Sander, I. L. 1988. Guidelines for regenerating Appalachian oak stands. In: Smith, H. C., A. W. Perkey, and W. E. Kidd, Jr., eds. Guidelines for regenerating Appalachian hardwood stands: workshop proceedings. May 24-26, 1988. SAF Publ. 88-03. West Virginia University Books. p. 189-198.

USING ROUNDUP AND OUST TO CONTROL INTERFERING UNDERSTORIES IN ALLEGHENY HARDWOOD STANDS

Stephen B. Horsley[1]

Abstract: Allegheny hardwood stands in the Pennsylvania portion of the type frequently contain dense understories of undesirable species such as hayscented fern (*Dennstaedtia punctilobula* (Michx.) Moore), New York fern (*Thelypteris noveboracensis* L.), grasses and sedges (*Carex* spp.), striped maple (*Acer pensylvanicum* L.) and beech (*Fagus grandifolia* Ehrh.). Once established, they interfere with the establishment of advance regeneration of desirable species. The use of herbicides is a practical means of controlling this vegetation. Initial small-plot studies showed that Roundup controlled all of the undesirable species. Under commercial application conditions, control of vegetation sometimes was less than predicted from the small-plot experiments. Three problems developed as a result of application techniques and subsequent shelterwood cutting in treated stands. First, the use of vehicle-mounted sprayers resulted in regeneration of ferns in the vehicle tracks from small segments of fern rhizome broken off by the treads during herbicide application. When these stands were subsequently shelterwood cut, the fern plants spread rapidly, completely revegetating the stand within a few years. Second, forest floor disturbance created by shelterwood cutting also stimulated germination of grass and sedge seed in the forest floor seed bank, precluding regeneration of desirable hardwoods. Third, striped maple kill was frequently less than expected. The fern, grass, and sedge regeneration problems were solved by using Oust, either alone or tank mixed with Roundup. Control of striped maple was increased by improving coverage of striped maple crowns with Roundup. Current guidelines recommend the use of Oust alone when ferns or ferns and a grass and sedge seed bank are the primary target species. Roundup alone is recommended where striped maple and beech are the primary targets. Where there is a combination of target species, a tank mix of Roundup and Oust is recommended. These herbicides are used in combination with several cutting techniques to obtain regeneration of Allegheny hardwoods.

INTRODUCTION

The cherry-maple or Allegheny hardwood type is a varient of the northern hardwood type found along the Pennsylvania-New York boundary, south through the Appalachians to the

[1]Principal Plant Physiologist, USDA Forest Service, Northeastern Forest Experiment Station, PO Box 928, Warren, PA 16365. The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture or the Forest Service of any product or service to the exclusion of others that may be suitable.

northern mountains of West Virginia and adjacent areas of Maryland, and in northeastern Ohio. Second- and third-growth stands in this type are composed primarily of black cherry (*Prunus serotina* Ehrh.), red (*Acer rubrum* L.) and sugar maple (*Acer saccharum* Marsh.), white ash (*Fraxinus americana* L.), yellow-poplar (*Liriodendron tulipifera* L.), and beech. In the Pennsylvania portion of the type, more than half of the stands have dense ground covers of herbaceous ferns, grasses and sedges, or woody understories of striped maple and beech root suckers, and are typically difficult to regenerate. Despite the presence of desirable species in the overstory, Allegheny hardwood stands usually lack the knee-high to waist-high regeneration commonly found in other eastern hardwood forest types.

This condition is a result of continuous browsing since the 1920's by a large population of white-tailed deer (*Odocoileus virginianus virginianus* (Boddaert)). Deer browsing has had three effects on forest vegetation: the numbers of seedlings are reduced, surviving seedlings are smaller, and species composition is altered (Marquis and Brenneman 1981; Tilghman 1989). Desirable species such as the maples, ash, and yellow-poplar are highly preferred by deer and tend to be eliminated when they are seedlings. Since black cherry is intermediate in food preference, any large desirable advance regeneration usually is black cherry. The ferns, grasses and sedges, striped maple, and beech are low in food preference and tolerant of understory shade. Thus, they not only remain in the understory but also expand into the growing space formerly occupied by desirable regeneration.

Expansion of undesirable plants also has been encouraged by thinnings which took place in many stands during the late 1950's and 1960's. Rhizome development of hayscented and New York fern and short husk grass (*Brachyelytrum erectum* Schreb.) is greatly accelerated in the partial shade of thinned or shelterwood seed cut stands. Seedlings of striped maple, which can remain in the understory for many years, grow rapidly when additional light is made available. Tolerant beech root suckers sustained by an older root system make surprisingly rapid growth in partially cut stands. Once these undesirable plants occupy the understory, they interfere strongly with the regeneration and establishment of desirable species, even when deer are excluded (Horsley and Marquis 1983). Interference by hayscented and New York fern is particularly serious because they form dense ground covers rapidly and the low intensity, high far-red shade light beneath them results in poor survival of black cherry and other desirable Allegheny hardwood species (Horsley 1986).

When the quantity of interfering plants becomes too great (for guidelines see Marquis et al 1991) steps must be taken to remove them before regeneration can be established. Neither mechanical methods nor fire are effective in the Allegheny hardwood type; however, herbicides are an effective, economical, and safe means of removing interfering plants and minimizing their regeneration so that desirable hardwood species can become established (Horsley et al in press).

THE INITIAL PRESCRIPTION

Initial small plot studies with several herbicides showed that the herbicide Roundup, manufactured by Monsanto, controlled hayscented and New York fern, short husk grass, and striped maple, and beech, and that the time of application was important in determining the application rate required for effective control (Horsley 1981; Horsley and Bjorkbom 1983). This was particularly true at low rates of application. For example, 95 percent or better control of 1- to 5-foot striped maple could be achieved with 1, 2, or 4 qt/acre of Roundup in early August or early September applications. But, 2-4 qt /acre were required to achieve this level of control if applications were made in early June or early July (Table 1).

Table 1.--Mean percent kill of 1-5 foot striped maple by Roundup applied at different rates and times.[a]

Application Rate	Month of Application				
(qt/acre)	Jun	Jul	Aug	Sep	Oct
1	53 d	81 a-d	95 ab	97 ab	57 cd
2	95 ab	87 abc	97 ab	97 ab	77 bcd
4	97 ab	97 ab	98 ab	99 a	90 ab

[a]Means followed by the same letter were not significantly different or $P \geq 0.05$ using Duncans New Multiple Range Test.

By restricting the application of Roundup to the time between early August and early September, the amount of herbicide needed could be minimized. This is important from both an economic and an environmental standpoint. The same sensitivity to time of application was observed when the 1 qt/acre rate was applied to striped maple stems of increasing size. More than 90 percent control of trees less than 1 foot tall could be obtained with any application date between early June and early October. However, control of larger trees was strongly dependent on application time; optimal control was achieved with early August to early September applications and was less at earlier or later times of application.

Weather conditions early in the growing season affect plant development. Therefore, differences in susceptibility to control by an herbicide can vary due to annual differences in weather conditions. For example, hayscented fern frond development is slower in a cool spring than in a warm spring (Table 2). Thus, early June applications of Roundup made in a year with a cool spring resulted in less control than a similar application in a warm spring.

Sensitivity to timing of Roundup application also was observed at the end of the growing season. When leaf yellowing begins, uptake and translocation of herbicide declines. Roundup applications after this time provided less control of all species we tested. The time of leaf yellowing, which occurs in mid-September in northwestern Pennsylvania, is a practical limit to Roundup application.

Table 2.--Air temperature, hayscented fern frond height, and hayscented fern control by a June 1 application of 1 qt/acre of Roundup.

Year	May Air Temp (°F)			Frond Height (in.)		Fern Control (%)
	Max	Min	Mean	May 1	June 1	
1976[a]	67.7	43.4	55.6	0-2	12	68
1977[b]	77.2	44.5	60.9	1-2	18-24	93

[a]From Climatological Data 81(5):4, Warren, Pennsylvania Station
[b]From Climatological Data 82(5):4, Warren, Pennsylvania Station

Our studies suggest that a high level of plant control can be achieved with 1 qt/acre of Roundup by restricting the time of application. Optimum dates for control of hayscented fern, New York fern, and short husk grass are from early July until leaf yellowing in mid-September. For striped maple, the optimum dates of application are from early August to leaf yellowing and for beech they are from early August to early October.

Once interfering plants are removed, the regeneration process can continue. Where interfering plants are not present, the most important factor determining success of regeneration is the establishment of large numbers of desirable seedlings before the final removal cut (Grisez and Peace 1973). A shelterwood seed cut leaving residual overstory stocking of about 60 percent hastens the development of large numbers of small seedlings (Horsley 1982; Marquis 1979). These seedlings do not grow much because the overstory is still dense enough to provide a light limitation. However, where deer impact is high, this is an advantage because the seedlings are less attractive to deer. Within 3 to 5 years, large numbers of seedlings usually become established, though the process can take longer.

Black cherry and red maple usually predominate in northwestern Pennsylvania stands and the speed with which adequate regeneration develops depends upon the basal area of black cherry greater than 8 inches dbh. Stands with at least 25 square feet of basal area/acre in black cherry usually develop adequate regeneration within a few years after the seed cut; stands with less black cherry often require a longer time. Once adequate regeneration has developed, the remaining overstory can be removed. In stands where herbicide has been applied, the overstory should be removed as soon as adequate regeneration develops to minimize reestablishment of any interfering plants that remain. Concentration of cutting in an area also reduces the impact of deer browsing (Horsley et al in press).

REFINEMENTS IN THE INITIAL PRESCRIPTION

Commercial application of Roundup in an herbicide-shelterwood cut system began in 1979. These applications used air-blast spray equipment mounted on tracked or rubber-tired vehicles. During the first 5 years it became apparent that refinements were required. Three problems developed as a result of application techniques and subsequent shelterwood cutting in treated stands. The first was that ferns were inadequately controlled in the area traversed by the vehicle carrying the sprayer; instead "fern tracks" were formed. Apparently, the metal cleats on tracked vehicles and the sharp edges of new rubber tires break off small segments of fern rhizome at the time of treatment, preventing translocation of Roundup into them. Over a period of 4 to 6 years in shelterwood cut stands, new fern plants regenerate and can reoccupy the understory before desirable hardwood regeneration becomes established. This process is abetted by variable numbers of small, isolated fern plants that develop from single unkilled rhizome buds, probably as a result of incomplete coverage of foliage with herbicide or incomplete translocation of herbicide within the plant.

The second problem was that, following the shelterwood seed cut, the stand sometimes regenerated to grasses and sedges rather than tree seedlings. The forest floor of most Allegheny hardwood stands contains a seed bank of grasses and sedges that germinate after disturbance. The skidding activities associated with the shelterwood seed cut provided the stimulus for germination in disturbed areas (Table 3). The greater the proportion of forest floor that was disturbed, the greater the amount of grass and sedge that developed. Little grass and sedge developed on undisturbed areas, even where a large seed bank was present. Typically, grass and sedge seeds germinated in the growing season after disturbance. Ground cover by these small plants was low in the first year, but during the second growing season after disturbance they grew to full size, greatly expanding in ground coverage. There was little expansion after the second year. Once a grass and sedge ground cover developed, the regeneration process was slowed so dramatically that little regeneration became established under our conditions that include an extremely high deer population.

Table 3.--Mean percent ground cover by newly germinated grass and sedge on disturbed and undisturbed plots 1, 2 and 3 years after disturbance.[a]

Disturbance	Years after Treatment		
	1	2	3
	(%)		
Roulette			
Disturbed	13[b] ± 20 a	0.4 ± 0.5 bcd	0 ± 0.2 bd
Undisturbed	1 ± 2 bc	0.4 ± 0.5 bcd	0 ± 0.3 bd
Kane			
Disturbed	43 ± 28 a	1 ± 0.6 b	
Undisturbed	2 ± 2 b	1 ± 1 b	

[a]Disturbance by year after treatment means at a location followed by the same letter were not significantly different at P ≥ 0.05 using the Bonferroni procedure. Each value is shown ± one standard deviation. n = 63.
[b]Each disturbance by year after treatment value is the mean of 21 observations.

The third problem was that, under commercial operating conditions, striped maple stems were not always controlled by Roundup as well as might be predicted from small-plot experiments.

Stems were almost always defoliated, but some were not killed and refoliated the following year from unkilled axillary buds. Increasing the rate of Roundup application from 1 to 4 qt/acre resulted in complete striped maple kill, but at an unacceptibly high cost.

The problems of "fern track" and grass and sedge reinvasion were solved by the inclusion of the residual herbicide Oust, manufactured by Du Pont, in tank mix with Roundup. A rate and time experiment to evaluate the effectiveness of Roundup in tank mix with Oust and Surflan in minimizing reestablishment of grass and sedge on disturbed sites showed that 2 to 4 oz/acre of Oust or 2 to 4 qt/acre of Surflan reduced reinvasion by grass and sedge originating in the forest floor seed bank for 2 or 3 years, respectively (Horsley, 1990b). Oust now has an EPA registration for this use, Surflan does not.

The study also pointed out that on sites where grass and sedge seed banks were large, herbicide alone was inadequate for reducing reinvasion and that steps were required to reduce the amount of forest floor disturbance on these sites. Another rate and time experiment with Oust alone showed that 2 oz/acre provided nearly complete control of hayscented and New York fern when applied between early July and early October (Table 4) (Horsley 1988).

Table 4.--Percent control of hayscented and New York fern and short husk grass 2 years after treatment with 2, 4, or 8 oz/acre of Oust. Oust was applied at the beginning of each month. Untreated control plots with which treated plots were compared had 100 percent ground cover by the target species.[a]

Rate of	Month of Application						
Application	May	Jun	Jul	Aug	Sep	Oct	Nov
Hayscented and New York Fern							
1	9 gh	52 def	98 ab	98 ab	98 ab	97 ab	27 fg
2	40 f	68 cde	99 a	98 ab	97 ab	98 ab	42 ef
3	75 cd	87 gh	100 a	99 a	99 a	99 a	69 cd
Short Husk Grass							
1	0 h	0 h	1 gh	1 gh	10 defg	2 fgh	6 efgh
2	0 h	0 h	10 defg	3 fgh	23 cde	18 def	10 defg
3	0 h	22 cde	50 ab	48 abcd	70 a	31 bcd	53 ab

[a]Month by rate of application means for each species followed by the same letter were not significantly different at $P \geq 0.05$ using the Bonferroni procedure.

Applications of Oust made earlier or later than these dates provided less control and results were rate-dependent. Oust did not provide adequate post emergent control of mature short husk grass plants, regardless of the rate (2 to 8 oz/acre) or time (early May to early November) of application (Table 4), nor did it have any effect on striped maple or beech (data not shown).

Efforts to increase the activity of Roundup on striped maple by the addition of adjuvants or other herbicides into the tank mix showed that none gave better results than Roundup alone (Table 5) (Horsley 1990a). Addition of adjuvants such as ammonium sulfate or EDTA to remove hard water ions that might bind the glyphosate molecule did not increase Roundup activity. Adjuvants that increase herbicide wetting and penetration of leaves, such as X-77 Spreader, Frigate Agricultural Adjuvant, and Sorbicide Herbicide Adjuvant, also did not increase control of striped maple above that obtained with Roundup alone. Inclusion of Sorbicide reduced herbicide effectiveness. Tank mixing Escort with Roundup gave the same results as Roundup alone, and a tank mix of 2,4-D amine with Roundup resulted in less control of striped maple than Roundup alone.

Table 5.--Mean percent kill of 5 - 20 foot tall striped maple stems by Roundup plus adjuvants and other herbicides 2 years after application.[a]

Herbicide Treatment	Percent Kill
Roundup (Control)[b]	81 a
Roundup + 1% EDTA	75 a
Roundup + 0.93% Ammonium Sulfate	71 a
Roundup + 1% Sorbicide Herbicide Adjuvant	51 b
Roundup + 0.5% Frigate Agricultural Adjuvant	86 a
Roundup + 0.5% X-77 Spreader	79 a
Roundup + 1 pt 2,4-D amine	65 b
Roundup + 1/4 oz Escort	70 a
Roundup + 1/2 oz Escort	70 a

[a]Percent kill means followed by the same letter were not significantly different at $P \geq 0.05$ using the Bonferroni procedure.
[b]Roundup was applied at the rate of 1 qt/acre in all treatments.

The most important factor controlling the proportion of striped maple stems killed by Roundup was distribution of the herbicide. The dilemma in ground spray operations with most air-blast spray equipment currently used in the Allegheny hardwood region is that the sprayer volute only allows the main blast of spray to be directed to vegetation in a limited vertical space. Aiming the volute horizontally results in good coverage of vegetation up to about 10 feet in height. Aiming the volute at an upward angle results in good coverage of vegetation from about 5 to 20 feet in height. Shorter vegetation is not well covered because much of the spray is intercepted by the larger vegetation.

Recently, Hammermill (International) Paper Co. purchased a Friend air-blast sprayer. The volute on the Friend has a vertical stack of nozzles that fills the air space with spray from the ground to a height of about 20 feet. Exceptionally good control of both short and tall vegetation in this space has been obtained in commercial spray operations using 1 qt/acre of Roundup in 25 gallons of water.

ECONOMIC CONSIDERATIONS

The decision to use herbicide in Allegheny hardwood stands is triggered by understory stocking (more than 30 percent) with ferns, grasses and sedges, striped maple, or beech (Marquis et al 1991). From a biological standpoint, Oust will effectively control ferns and will provide preemergent reduction of ground cover by grasses and sedges originating from the forest floor seed bank on disturbed areas. Oust has no activity on striped maple or beech. Roundup will control all of the interfering plants present in Allegheny hardwood stands but it has no residual soil activity, and will not provide preemergent control of grass and sedge originating in the forest floor seed bank after soil disturbance.

In commercial operations, fern tracks also are a problem when Roundup is used alone. In stands with ferns alone or with ferns and a grass and sedge seed bank, Oust provides the most effective control at the least cost. In stands with interfering striped maple and/or beech understories, Roundup is the herbicide of choice. Roundup should be applied at the rate of 1 qt/acre and Oust at the rate of 2/acre. Most stands have a combination of ferns, grasses and sedges, striped maple, and beech. In these, Roundup and Oust should be tank mixed with 0.5 percent of a non-ionic surfactant, such as X-77 or Frigate. When a combination of interfering plants is present, the decision to use one herbicide or a tank mix is an economic one based on the stand value at maturity lost by not adding the second herbicide to control interfering plants not controlled by the first herbicide. For example, let us assume that the cost of applying a single herbicide, including both the chemical and application costs, is $100/acre and that the cost of adding a second herbicide brings the total cost to $115/acre. Furthermore, let us assume that Allegheny hardwood stands are managed on an 80-year rotation, have values ranging between $1000 and $5000/acre at that age, and that real (no inflation, no after-inflation increase in timber prices) interest rates range from 3.5-5 percent. Under these conditions, the difference in discounted cost between using one and using two herbicides is $235/acre at 3.5 percent interest and $743/acre at 5 percent interest over 80 years. For stands valued at $5000/acre, $250/acre is lost for every 5 percent of stand area lost to plants not killed by the first herbicide; for stands valued at $1000/acre, $50 is lost for every 5 percent of the stand area lost to plants not killed by the first herbicide. A high-value stand ($5000/acre at maturity) needs less than 5 percent of the area covered by unkilled interfering plants to warrent use of the second herbicide if the interest rate is 3.5 percent, or 15 percent of the area covered by unkilled interfering plants to warrent use of the second herbicide if the interest rate is 5 percent. Comparable values for a low-value stand ($1000/acre at maturity) are 23 percent and 75 percent, respectively. Consideration of the wide range of conditions encountered in the Allegheny forest region suggests that the second herbicide should be added when more than about 15 percent of the regeneration sample plots have interfering plants that would not be killed by the first herbicide.

COMBINING HERBICIDE WITH CUTTING PROCEDURES

In most cases, herbicide is sprayed in the uncut stand, followed by a shelterwood seed cut. However, where large grass and sedge seed banks are present, herbicide alone was not effective in preventing revegetation of the site (Horsley 1990b). Reducing the amount of disturbance in addition to using herbicide is required in this situation. Modifying the herbicide and cutting sequence used to regenerate the stand is an effective way to minimize grass and sedge regeneration. Since shelterwood cutting is the primary source of disturbance that stimulates grass and sedge regeneration, reversing the herbicide and cutting sequence (shelterwood seed cut then herbicide) induces grass and sedge regeneration before the herbicide is applied. The herbicide removes these interfering plants. Since no more disturbance occurs in the stand, regeneration develops unhindered. When this procedure is used, steps must be taken to keep slash close to the ground so that it does not interfere with movement of the sprayer in the stand.

Another alternative is to delay any cutting in the stand until regeneration is established, then make the final removal cut. This procedure is useful in stands with less than 75 percent overstory stocking, since there is enough light to allow desirable seedling establishment. It also avoids soil disturbance which might allow interfering plants such as grasses and sedges to recapture the stand before regeneration becomes established. When the final removal cut is made, the well-established tree seedlings rapidly outgrow any interfering plants that have developed.

LITERATURE CITED

Grisez, T.J., and M.R. Peace. 1973. Requirements for advance reproduction in Allegheny hardwoods-an interim guide. USDA For. Serv. Res. Note NE-180. 5p.

Horsley, S.B. 1981. Control of herbaceous weeds in Allegheny hardwood forests with herbicides. Weed Sci. 29:655-662.

Horsley, S.B. 1982. Development of reproduction in Allegheny hardwood stands after herbicide-clearcuts and herbicide-shelterwood cuts. USDA For. Serv. Res. Note NE-308. 4p.

Horsley, S.B. 1986. Evaluation of hayscented fern interference with black cherry. Amer. J. Bot. 73:668-669.

Horsley, S.B. 1988. Control of understory vegetation in Allegheny hardwood stands with Oust. North. J. Appl. For. 5:261-262.

Horsley, S.B. 1990a. Tank mixing Roundup with adjuvants and other herbicides for striped maple control. North. J. Appl. For. 7:19-22.

Horsley, S.B. 1990b. Control of grass and sedge in Allegheny hardwood stands with Roundup-residual herbicide tank mixes. North. J. Appl. For. 7:124-129.

Horsley, S.B., and J.C. Bjorkbom. 1983. Herbicide treatment of striped maple and beech in Allegheny hardwood stands. For. Sci. 29:103-112.

Horsley, S.B. and D.A. Marquis. 1983. Interference by weeds and deer with Allegheny hardwood reproduction. Can. J. For. Res. 13:61-69.

Horsley, S.B., L.R. Auchmoody and R.S. Walters. in press. Regeneration principles and practices. In Quantitative silviculture for hardwood forests of the Alleghenies. USDA For. Serv. Gen. Tech. Rep.

Marquis, D.A. 1979. Shelterwood cutting in Allegheny hardwoods. J. For. 77:140-144.

Marquis, D.A., and R. Brenneman. 1981. The impact of deer on forest vegetation in Pennsylvania. USDA For. Serv. Gen. Tech. Rep. NE-65. 7p.

Marquis, D.A., R.L. Ernst and S.L. Stout. 1991. Prescribing silvicultural treatments in hardwood stands of the Alleghenies (Revised). USDA For. Serv. Gen. Tech. Rep. NE-96. 90p.

Tilghman, N.G. 1989. Impacts of white-tailed deer on forest regeneration in northwestern Pennsylvania. J. Wildl. Manage. 53:524-532.

TREE SHELTERS INCREASE HEIGHTS OF PLANTED NORTHERN RED OAKS

Douglas O. Lantagne[1]

Abstract: A clearcut in southern Michigan was planted to 2-0 northern red oak (*Quercus rubra* L.) seedlings in the spring of 1987. Four treatments included: control (clearcut harvest only), woody brush control, plastic tree seedling shelters 122 cm tall, and woody brush control plus tree seedling shelters. After three growing seasons, the seedlings planted in tree shelters were 53 cm taller than unsheltered seedlings. Sheltered seedlings grew 18 cm/year more than unsheltered seedlings over that same period. Over 65 per cent of sheltered seedlings were 122 cm tall or taller after three growing seasons compared to only 8.5 percent of unsheltered seedlings. The height growth of sheltered seedlings was related to the increased extension of the initial growth flush. The number of growth flushes was similar for sheltered and unsheltered seedlings. Tree shelters thus accelerated the growth of planted red oak into dominant and codominant positions on this clearcut site after three growing seasons. The increased elongation may result from seedlings modifying their growth habit, rather than an a result of increased stem dry weight.

INTRODUCTION

Planting oak as an alternative to natural regeneration has often resulted in failure caused by the slow growth of planted seedlings relative to the rapid growth of competing vegetation (Johnson et al. 1986). However, release of planted oak seedlings from competing vegetation alone does not guarantee success (Hilt 1977). Johnson et al. (1986) recommended that tree planters control undesirable woody vegetation before harvest, establish a medium density shelterwood, use large-diameter oak seedlings, and remove the overstory after three years. Tuley (1983), working in Great Britain, used individual tree shelters similar to those shown in Figure 1 to establish planted oak seedlings. Tree shelters protect planted hardwood seedlings from animal damage and improve seedling survival and height growth. One measure of their effectiveness is reflected in the estimated number of tree shelters used in Great Britain, which increased from 80 in 1979 to over 6 million in 1986 (Potter 1987).

This study investigated oak planting with tree shelters as a method of establishing oak in a clearcut. Lantagne et al. (1990) reported increased growth of northern red oak in tree shelters in a southern Michigan clearcut after two years. This paper presents 3-year results of that study.

---

[1]Associate Professor of Forestry, Michigan State University, Department of Forestry, 126 Natural Resources Building, East Lansing, MI 48824.

METHODS

The study was established in an oak-hickory forest at the W.K. Kellogg Experimental Forest in southern Michigan. Soils were predominantly sandy loam (Alfisols) developed from stony glacial drift on a rolling, well drained site. Average red oak site index (base age 50) for the study area was 66. The study area underwent a shelterwood seed cut in 1954 and a removal cut in 1964 as part of a previous oak regeneration study (Rudolph and Lemmien 1976). Before the study was established, all stems > 5 cm dbh were removed in a whole-tree clearcut harvest in the fall of 1986. All remaining stems > 2.54 cm dbh were removed by hand.

Figure 1. Tops of 1.2-m-tall tree shelters in a woody brush control plot after two growing seasons.

A 2 X 2 factorial combination of treatments was replicated on four 0.5 hectare blocks in a split-plot design. A 0.1-hectare buffer zone was established around each block. Each 0.4-hectare block was split in half to accommodate brush control treatments (main plots). Each main plot was then split in half to accommodate tree shelter treatments (split plots). The four treatments were: control (no woody brush control, no shelters); woody brush control only;

shelters only, and woody brush control and shelters. All treatments were randomly applied within replications.

Woody brush control occurred in five steps, two before harvest and three after harvest. The first steps were a prescribed burn in the spring of 1986 and a basal application of triclopyr and oil to non-oak species in the summer of 1986. The final three steps were post-harvest basal applications of triclopyr and oil to non-oak species during the summers of 1987, 1988 and 1989.

Plastic shelters were constructed from 51 X 122 X 0.63 cm sheets of corrugated polyethylene plastic. Each sheet cost about $1.50. Individual sheets were bent and stapled to 2.5- X 2.5-cm stakes driven into the ground next to planted oak seedlings. Shelters were placed as close as possible to the soil surface but were not sealed at the soil surface or along the stake used for support. Stakes were also driven into the ground next to all unsheltered seedlings.

Northern red oak acorns collected from the study site in the fall of 1984 were immersed in water. "Sinkers" were collected and 86 per square meter were sown in a prepared nursery bed. Following the first growth flush in June 1986, seedlings were undercut at 20 cm to encourage development of a fibrous root system. The 2-0 northern red oak seedlings were lifted in mid-April 1987, sorted to a minimum 1-cm root collar diameter, root pruned to 20 cm, wrapped and stored at 1° C until planting. Seedlings were planted over a two day period in late April 1987 with dibble bars at a 3.4- X 3.4-meter spacing for a total of 90 oak seedlings per treatment. After planting, seedlings were clipped 18 cm above the ground-line. Tree shelters were then installed. All work was completed by May 1, 1987.

Six 4 m^2 permanent regeneration survey plots were randomly placed in the areas without brush control. Seedlings and sprouts of all naturally occurring woody species in the survey plots were counted at the end of the 1988 growing season. Heights of all planted northern red oak seedlings were measured in the fall of 1989. Number and length of flushes were measured on 40 trees in three of the four brush control plots in the spring of 1990. Twenty trees above 125 cm were randomly selected from the shelter plots and the 20 tallest trees from brush-control-only plots.

Analysis of variance and Duncan's new multiple range test were used to test for significant differences among treatment means. Survival percentages were transformed with the arcsine procedure and growth flush data with the square root procedure (Little and Hills 1978). Chi-square analysis was used to test for differences in height class distribution between the sheltered and unsheltered seedlings.

RESULTS

Total vegetative cover averaged 85 to 90 percent across all treatment plots during the first three growing seasons. The predominant species included *Rubus* spp., goldenrod (*Solidago nemoralis* Ait.), wild grape (*Vitis* spp.), aster (*Aster pilosus* Willd.), pokeweed (*Phytolacca* *americana* L.), daisy fleabane (*Erigeron strigosus* Muhl.) and bull thistle (*Cirsium vulgare* (Savi) Tenore). Two years after clearcut harvest, there was an average of 1,611 natural oak seedlings per hectare. Non-oak reproduction averaged over 12,429 stems per hectare.

Brush control had no significant affect on total height of planted red oak ($P = 0.25$), but heights of sheltered and unsheltered trees differed significantly ($P < 0.0001$)(Table 1). Seedling survival and height for sheltered seedlings were significantly greater than unsheltered seedlings (Table 2). The height increase of sheltered trees was 1.7 times greater than that of unsheltered trees.

Table 1.--Analysis of variance for total tree height for planted trees.

Factors	DF	Mean Square	F Ratio
Main Plots			
Replication (Rep)	3	242.74	
Brush Control (BC)	1	23.01	0.67
Rep X BC (Error a)	3	102.98	
Split Plots			
Shelters (S)	1	11313.96	199.15***
BC X S	1	37.11	0.45
Error	6	56.81	

*** Significant ($p < 0.0001$)

Table 2.--Effect of shelters and brush control on survival and height of planted northern red oak seedlings after the third growing season.[1]

Treatments	Survival	Total Height	Height Increase[2]
	--(%)--	---(cm)---	---(cm)---
Main Plots			
Brush Control	94a	105(1.9)a	29(1.1)a
No Brush Control	95a	102(1.8)a	25(1.2)a
Split Plots			
Shelter	98a	130(1.7)a	34(1.2)a
No Shelter	90b	77(1.4)b	20(1.0)b

[1]Means (standard errors) within the columns followed by the same letter are not significantly different ($p < 0.05$) using Duncan's New Multiple Range Test.
[2]Height increase was determined by subtracting 1988 total height from 1989 total height for each individual seedling measured.

Figure 2 illustrates the effect of shelters on seedling height class distribution. More sheltered than unsheltered seedlings were in the larger height size classes. A Chi-square analysis indicated that the distributions were significantly different (P < 0.0001). After three growing seasons, over 65 percent of the sheltered seedlings were above shelter height (122 cm), compared to only 8.5 percent of unsheltered seedlings.

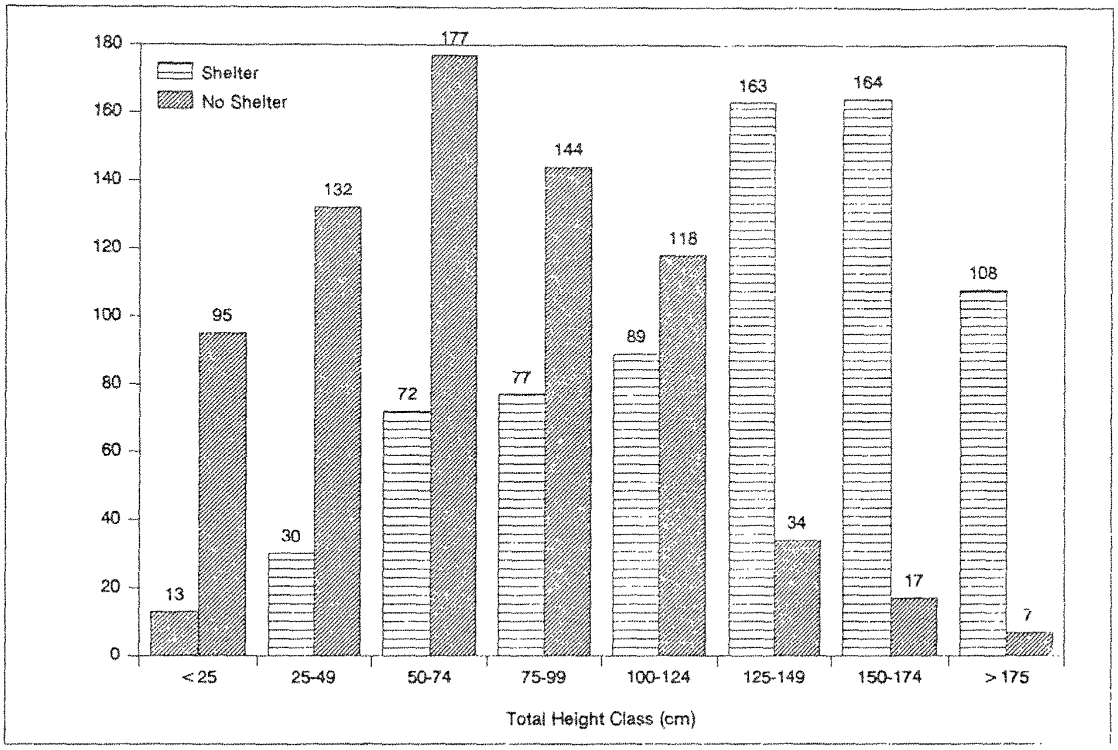

Figure 2. Height distributions of sheltered and unsheltered northern red oak seedlings after the third growing season. (Distributions of the two classes of seedlings differ significantly based on Chi-square (X^2 = 487, p < 0.0001).

Analysis of variance indicated that shelters increased the number of growth flushes in 1987 (P = 0.064) and 1988 (P = 0.088), but not in 1989 (P = 0.423). The average length of the initial growth flush was also affected by shelters in 1988 (P = 0.002) and 1989 (P = 0.016). These initial flushes averaged 13 cmgreater in 1988 and 12 cm greater in 1989 than unsheltered trees (Table 3). The average length of secondary growth flushes did not differ significantly between sheltered and unsheltered trees.

DISCUSSION

Tree shelters can improve both survival and height growth of oak seedlings (Tuley 1983, Lantagne et al. 1990). This was reaffirmed by the third year data,which showed a greater increase in total height and growth for sheltered seedlings than for unsheltered controls

Table 3.--Effect of shelters and brush control on the number and length of growth flushes of planted northern red oak seedlings for the first three growing seasons.

Treatments	Number of Flushes[1]			Length of First Flush[2]		
	1987	1988	1989	1987	1988	1989
				(cm)		
Shelters/Brush control	33a	32a	37a	23a	40a	39a
Brush control only	27b	28b	36a	19a	27b	27b

[1]Means were derived by counting the total number of flushes for twenty trees for each treatment in each of three replications. Means within the columns followed by the same letter are not significantly different ($p < 0.1$) using Duncan's New Multiple Range Test.
[2]Means within the columns followed by the same letter are not significantly different ($p < 0.05$) using Duncan's New Multiple Range Test.

(Figure 3). Sheltered red oak seedlings averaged 53 cm taller than unsheltered seedlings after three growing seasons. Average height increases over the past three growing seasons show that sheltered seedlings grew 18 cm/year more than unsheltered seedlings (Figure 3). This additional growth has placed over 65 percent of the sheltered seedlings in a dominant crown position in areas with woody brush suppression and the same percentage in an intermediate or codominant crown position in areas with unsuppressed woody vegetation. Only 8.5 percent of unsheltered seedlings reached an equivalent height of at least 122 cm after three growing seasons and most were in a subordinate canopy position.

The increased growth of sheltered seedlings over unsheltered seedlings has been attributed to several possible factors: (1) a microenvironment that promotes multiple flushes, (2) a reallocation of growth from roots, stem caliper and branches to the terminal leader and (3) physical protection from breakage and animal browse (Lantagne et al. 1990). The data showed that the increased growth of the initial terminal flush was more important to total height growthof the seedling than an increased number of flushes. During the second and third growing seasons, sheltered trees averaged 12.5 cm/year more elongation of their first growth flush than unsheltered trees.

Sheltered trees exhibit three physical stem characteristics which unsheltered trees do not exhibit: longer stems, few, if any branches and limited caliper growth. These characteristics indicate that increased height growth of sheltered seedlings may not be synonymous with increased stem dry weight. Rather, sheltered seedlings may simply be modifying their height growth at the expense of structural stability and branch formation. As a consequence of less stem caliper, trees must be supported for two years after exiting the shelters. The affect of shelters on root growth has not been studied. However, Johnson (1979) working with northern red oaks in a root regeneration study found no reduction in the rate of root growth during periods of shoot elongation. Therefore, increased shoot elongation of sheltered seedlings may not be negatively impacting root system establishment.

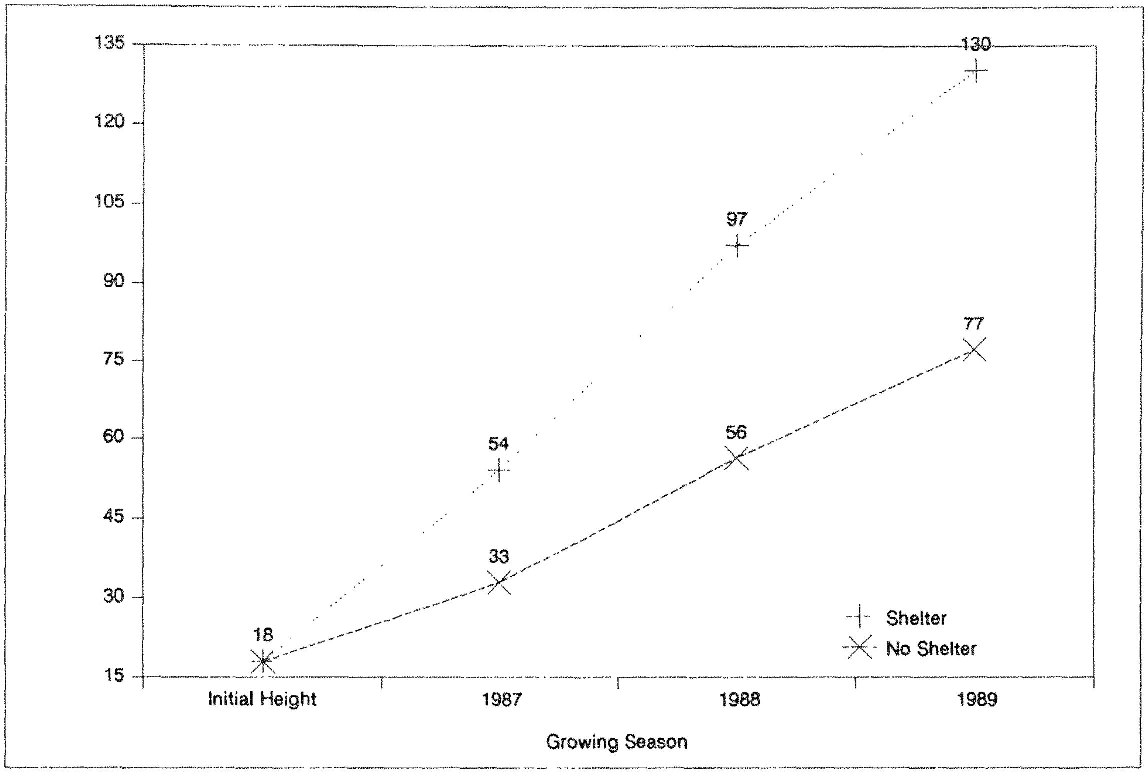

Figure 3. Means Heights of surviving planted northern red oak seedlings. (All seedlings were top pruned at 18 cm above the groundline immediately following planting. Sheltered seedlings were significantly taller at the end of each growing season.)

SUMMARY

Many sheltered trees grew into dominant and codominant crown positions, where÷áas few other planted seedlings or natural oak reproduction did. The mechanism for increased growth is not a result of increased number of growth flushes, but an increase in the amount of elongation of the initial growth flush. This increased elongation may result from seedlings modifying their growth habit, rather than an a result of increased stem dry weight. The cost and environmental issues associated with the use of plastic tree shelters for oak regeneration have to be evaluated and discussed as additional growth data is collected.

LITERATURE CITED

Hill, J.P and D.I. Dickmann. 1988. A comparison of three methods for naturally reproducing oak in southern Michigan. North. J. Appl. Forestry 5:113-117.

Hilt, D.E. 1977. Introduction of black walnut and northern red oak seedlings in an upland hardwood forest in southeastern Ohio. USDA Forest Serv., NE For. Exp. Station Res. Note NE-241.

Johnson, P.S., C.D. Dale, K.R. Davidson and J.R. Law. 1986. Planting northern red oak in the Missouri Ozarks: A prescription. North. J. Appl. Forestry 3:66-68.

Johnson, P.S. 1979. Growth potential and field performance of planted oaks. p. 113-119. In: Proc. 1979 John S. Wright Forestry Conference, Regenerating Oaks in Upland Hardwood Forests, Purdue University, West Lafayette, IN.

Lantagne, D.O., C.W. Ramm and D.I. Dickmann. 1990. Tree shelters increase heights of planted oaks in a Michigan clearcut. No. J. Appl. For. 7(1):24-26.

Little, T.M. and F.J. Hill. 1978. Agricultural Experimentation: Design and Analysis. John Wiley and Sons, New York. 350p.

Loftis, D.L. 1983. Regenerating southern Appalachian mixed hardwood stands with the shelterwood method. So. J. Appl. For. 7:212-217.

Lorimer C.G. 1989. The Oak Regeneration Problem: New evidence on causes and possible solutions. Forest Resources Analyses, Department of Forestry, U. of Wisconsin-Madison, R-3484. 31p.

Potter, M. 1987. Advances in tree shelter research and design. Oxford Forestry Institute Occasional Papers No. 34. National Hardwoods Programme. Report of the Seventh Meetings. P.S. Savil (ed). 7p.

Rudolph, V.J. and W.A. Lemmien. 1976. Silvicultural cuttings in an oak-hickory stand in Michigan: 21 year results. pp. 431-452. In: Proceedings, First Central Hardwood Forest Conference, J.S. Fralish, G.T. Weaver and R.C. Schlesing÷áer (eds). So. Illinois University, Carbondale, IL.

Tuley, G. 1983. Shelters improve the growth of young trees in forest. Quart. J. Forestry. 77:77-87.

MAMMAL CACHING OF OAK ACORNS IN A RED PINE AND A MIXED-OAK STAND

Eugene R. Thorn and Walter M. Tzilkowski[1]

Abstract: Small mammal caching of oak (*Quercus* spp.) acorns in adjacent red pine (*Pinus resinosa*) and mixed-oak stands was investigated at The Penn State Experimental Forest, Huntingdon Co., Pennsylvania. Gray squirrels (*Sciurus carolinensis*) and mice (*Peromyscus* spp.) were the most common acorn-caching species. Acorn production was estimated at 104,200 red oak group acorns/ha and 80,250 white oak group acorns/ha. Acorn caches in the red pine stand were estimated at 900 red oak acorns/ha and 650 white oak acorns/ha. In contrast, in the mixed-oak stand 45,350 red oak acorns/ha and 24,150 white oak acorns/ha were cached. Gray squirrels cached 38% of the acorns produced; 98% of the acorns were cached in the mixed-oak stand. Gray squirrels cached 38% of the acorns produced; 98% of the acorns were cached in the mixed-oak stand.

INTRODUCTION

In the northeastern United States, foresters and wildlife managers consider oaks (*Quercus* spp.) to be the most important tree species (Martin et al. 1951, Shaw 1971). Cahalane (1942), Janzen (1971) and Potter (1978) reported dispersal and planting of acorns by mammals and birds are beneficial for oak regeneration. However, the role of small mammals in oak regeneration is unclear; Marquis et al. (1976) and Gottschalk (1983) reported mammal predation of acorns and small seedlings has a serious negative effect on oak regeneration and contributes to regeneration failure.

Size and frequency of acorn crops vary yearly and are unpredictable (Sharp and Chisman 1961). Size and viability of acorns also differ with geographic location (Marquis et al. 1976). Acorn crops vary from 0 to 250,000+ acorns/acre (Olson and Boyce 1971). Acorns ripen and are dispersed from late August to early December. Acorns of the white oak group mature in one year, whereas acorns of the red oak group require two years (Olson 1974). In autumn white oak acorns germinate immediately upon dropping and the radicle may reach a depth of 8 inches before onset of cold weather (Watt 1979). Red oak acorns do not germinate until spring, as they require 32-41°F and moist stratification for at least 30-60 days (McQuilken

[1]Wildlife Biologist, West Virginia Division of Natural Resources, Wildlife Resources Section, Simon, W. Va. 24882, and Associate Professor of Wildlife Science, School of Forest Resources, The Pennsylvania State University, University Park, PA 16802, respectively.

Table 1.--Red and white oak acorns/ha and caps/ha on the ground at bi-weekly intervals (n=40 4-m2 plots per interval).

	Red Oak				White Oak			
	Acorns		Caps		Acorns		Caps	
Week	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
21 Sep.	39,550	28,850	8,550	6,250	25,750	27,325	5,575	6,800
5 Oct.	66,050	39,425	46,800	25,650	35,325	33,225	30,375	25,175
19 Oct.	18,300	16,225	72,825	42,950	950	1,750	55,125	48,900
2 Nov.	2,200	3,300	82,200	51,125	450	1,175	61,625	48,450
16 Nov.	500	1,150	104,200	51,400	325	825	80,250	58,000

Table 2.--Red and white acorns cached/ha in the oak and red pine stands per sample period (n = 50 4-m2 plots).

Elasped	Red Pine				Oak			
time	Red Oak		White Oak		Red Oak		White Oak	
(weeks)	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
3	450	1,200	300	825	8,550	7,700	1,350	1,700
5	500	1,125	450	1,075	37,100	22,750	18,550	27,700
7	700	1,425	650	1,225	43,650	28,450	24,150	22,850
9	900	1,950	500	1,125	45,350	27,650	15,400	16,375

Comparison of total acorn production (caps) (184,450/ha) to total peak caches (69,500/ha) indicated 37.7% of total acorn production was reflected in caches. Activity of small mammals in the oak stand resulted in 70,000 well-distributed caches/ha. Gray squirrels were the important species in acorn dispersal. Their style of caching, a single acorn buried approximately 3 cm deep, may be beneficial for acorn storage and germination. Core (1971) reported gray squirrels are so important in dispersal that a diminishing squirrel population could have adverse effects on acorn distribution. Gray squirrels used many of the 70,000 cached acorns/ha, however, nondormancy of white oak may have added seedlings that may not have become established otherwise. Chew (1978:175) stated, "The number of seeds that are consumed can easily be overly impressive . . . If there has been a long evolutionary relationship of plant and predator, the loss of 99% of the plant's seed crop to the granivore is not necessarily of any consequence to the plant's future destiny and productivity. Measurement of this loss per se is not proof of an effect of the seed predator on the plant."

Gray squirrels cached 38% of the acrons produced; the mixed-oak stands was preferred for caching. This information could be used as a basis for intensely managing squirrel populations in areas where enhancement of oak reproduction is a priority. Some options would be leaving den trees when cutting, altering rotation length to favor squirrels, and manipulating the opening date of squirrel hunting season. Perhaps squirrel hunting season should open after the majority of acorns has fallen and been cached, to enhance oak regeneration potential.

LITERATURE CITED

Barnett, R. J. 1977. The effect of burial by squirrels on germination and survival of oak and hickory nuts. Am. Midl. Nat. 98:319-330.

Begon, M. 1979. Investigating animal abundance. University Park Press, Baltimore, Md. 97 pp.

Byrne, J. G. 1961. An ecological study of the mixed oak stands in central Pennsylvania. M.S. Thesis, The Pennsylvania State Univ., University Park. 68 pp.

Cahalane, V. H. 1942. Caching and recovery of food by the western fox squirrel. J. Wildl. Manage. 6:338-352.

Chew, R. M. 1978. The impact of small mammals on ecosystem structure and function. Pages 167-180 in D. P. Snyder, ed., Populations of small mammals under natural conditions. Vol. 5, Special Publ. Series, Pymatuning Lab. of Ecol., Univ. of Pittsburgh.

Core, E. L. 1971. Silvical characteristics of the five upland oaks. Pages 19-22 in Proc. oak symposium. U.S. Dep. of Agric. N.E. For. Exp. Sta., Upper Darby, Pa.

Flyger, V. F. 1959. A comparison of methods for estimating squirrel populations. J. Wildl. Manage. 23:220-223.

Gottschalk, K. W. 1983. Management strategies for successful regeneration: Oak-hickory. Pages 190-213 in Proc. regenerating hardwood stands. 1983 Penn. State Forestry Issues Conf., University Park, Pa.

Griffin, J. R. 1971. Oak regeneration in the upper Carmel Valley, California. Ecology 52:862-868.

Janzen, D. H. 1971. Seed predation by animals. Ann. Rev. Ecol. Syst. 2:465-492.

Marquis, D. A., P. L. Eckert, and B. A. Roach. 1976. Acorn weevils, rodents, and deer all contribute to oak regeneration difficulties in Pennsylvania. U.S. Dep. Agric. For. Serv. Res. Pap. NE-356. 5 pp.

Martin, A. C., H. S. Zim, and A. L. Nelson. 1951. American wildlife and plants: A guide to wildlife food habits. Dover Pub. Inc., New York, N.Y. 500 pp.

M'Closkey, R. T. 1980. Spatial patterns in sizes of seeds collected by four species of heteromyid rodents. Ecology 61:486-489.

McQuilkin, R. A. 1983. Silvical factors affecting the regeneration of oaks and associated species in Pennsylvania. Pages 37-65 in Proc. regenerating hardwood stands. 1983 Penn. State Forestry Issues Conf., University Park, PA.

Montgomery, S. D., J. B. Whelan, and H. S. Mosby. 1975. Bioenergetics of a woodlot gray squirrel population. J. Wildl. Manage. 39:709-717.

Nixon, C. M., D. M. Worley, and M. W. McClain. 1968. Food habits of squirrels in southeast Ohio. J. Wildl. Manage. 32:294-308.

O'Farrel, M. J., D. W. Kaufman, and D. W. Lundahl. 1977. Use of live-trapping with the assessment line method for density estimations. J. Mammal. 58:575-582.

Olson, D. F., and S. G. Boyce. 1971. Factors affecting acorn production and germination and early growth of seedlings and seedling sprouts. Pages 44-48 in Proc. oak symposium. U.S. Dep. Agric. N.E. For. Exp. Sta., Upper Darby, Pa.

Olson, D. F. 1974. *Quercus* L. oak. Pages 692-703 in C. S. Shopmeyer, ed., Seeds of woody plants in the United States. U.S. Dep. Agric., For. Serv. Agr. Handb. 450.

Potter, G. L. 1978. The effect of small mammals on forest ecosystem structure and function. Pages 181-187 in D. P. Snyder, ed., Populations of small mammals under natural conditions. Vol. 5, Special Publ. Series, Pymatuning Lab of Ecol., Univ. of Pittsburgh.

Sharp, W. H., and H. H. Chisman. 1961. Flowering and fruiting in the white oaks. I. Staminate flowering through pollen dispersal. Ecology 42:365-372.

Shaw, S. P. 1971. Wildlife and oak management. Page 84-89 in Proc. Oak Symposium. U.S. Dep. Agric. N.E. for Exp. Sta., Upper Darby, PA.

Stapanian, M. A., and C. C. Smith. 1978. A model for seed scatter-hoarding: coevolution of fox squirrels and black walnuts. Ecology 59:884-896.

Watt, R. F. 1979. The need for adequate advance regeneration in oak stands. Pages 11-17 in H. A. Holt and B. C. Fischer, eds., Proc. regenerating oaks in upland hardwood forests. Purdue Res. Foundation, West Lafayette, Ind.

ROLE OF SPROUTS IN REGENERATION OF A WHOLE-TREE CLEARCUT IN CENTRAL HARDWOODS OF CONNECTICUT

C. Wayne Martin and Louise M. Tritton[1]

Abstract: Stump sprouts were the single most important type of regeneration in a central hardwood forest in Connecticut during the first 5 years after whole-tree clearcutting. Herbs, shrubs, tree seedlings, and stump sprouts were inventoried using stratified permanent plots on a 6-ha watershed during the first, third, and fifth years after harvest. The first year after cutting 1,540 kg ha^{-1} of living biomass, including herbs, shrubs, and tree seedlings and sprouts, accumulated on the watershed. Of that, 54% was in tree seedlings and sprouts from stumps < 10 cm, and 13% in sprouts from stumps ≥ 10 cm. Oaks produced the most sprout biomass from large stumps, followed by maples and chestnut. By the fifth year, 17,990 kg ha^{-1} of living biomass had accumulated with 56% in tree seedlings and sprouts from small stumps, and 15% in sprouts from large stumps. Approximately 28% of the initial number of sprouts from large stumps had survived through year 5, and sprout biomass of oaks was still greater than that of maples and chestnut. Our study indicates that sprouts are highly active in the initial accumulation of biomass and nutrients after harvest.

INTRODUCTION

Rapid revegetation of sites following clearcutting can reduce soil erosion, conserve nutrients, and promote the development of a new forest. Stump sprouts are one means for rapidly establishing many hardwood species (Smith 1986). Their prevalence has been documented after clearcutting in Tennessee (Mann 1984), North Carolina (Boring et al. 1981), West Virginia (Wendel 1975), Georgia (Miller and Phillips 1984), and Michigan (Mroz et al. 1984). Factors that influence the potential contribution of sprouts to development of a commercially desirable forest include rate of growth and quality of sprouts (Wendel 1975); species, diameter, and height of parent stumps (Miller and Phillips 1984, Solomon and Blum 1967); mortality and long-term survival of sprouts (Johnson 1977, McIntyre 1936); and susceptibility of sprouts to decay (Jones and Raynal 1987, Roth and Hepting 1943). A better understanding of the role of sprouts in revegetation of hardwood sites is needed to guide logging practices and forest management.

As part of long-term research on the effects of whole-tree harvesting on a Connecticut hardwood forest ecosystem (Hornbeck et al. 1990, Tritton et al. 1987), we are following the

[1]Research Foresters, USDA Forest Service, Northeastern Forest Experiment Station, Durham, NH, and Burlington, VT, respectively.

species composition, biomass, and nutrient content of revegetation on the site (Martin et al. 1987). This paper summarizes data from the first, third, and fifth years after cutting in order to evaluate: 1) Whether stump sprouts are a viable means for regenerating a commercially desirable Connecticut hardwood forest, 2) The importance of stump sprouts in conserving nutrients on the site immediately after cutting, thereby acting to maintain site fertility; and 3) How management practices influence the importance of stump sprouts.

THE STUDY SITE

The study site is a 6 ha forested watershed located on the Cockaponset State Forest in Chester, CT. The soils of the upper slopes generally are of the Hollis-Chatfield-Rock association, loamy, mixed, mesic Lithic Dystrochrepts, which consist of shallow, somewhat excessively drained soils with occasional outcrops of exposed bedrock. The bedrock is of the upper Middletown formation, an assemblage of gneisses and schists with inclusions of sillimanite quartz and pegmatite. The soils of the lower slopes are deep, well-drained, coarse, loamy, mixed, mesic Typic Dystrochrepts of the Chatfield-Canton association. The soils of the valley floor are poorly drained, acidic, coarse-loamy, mixed, mesic Aeric Haplaquepts of the Leicester series (USDA Soil Conserv. Serv. 1981).

Prior to whole-tree clearcutting, the watershed supported an 80- to 110-year-old mixed age oak-birch-maple forest typical of Connecticut and southern New England (Martin et al. 1987, Stephens and Waggoner 1980). The basal area of the trees and shrubs larger than 2 cm dbh was 23 m^2 ha^{-1}, with a density of 1,163 stems ha^{-1}. The aboveground living biomass was 168 metric tons ha^{-1}, with 303 kg ha^{-1} of total nitrogen, 589 kg ha^{-1} of calcium, and 180 kg ha^{-1} of potassium (Hornbeck et al. 1990, Tritton et al. 1982).

In the winter of 1981-82, the watershed was whole-tree clearcut. All living and standing dead trees greater than 5 cm dbh were cut. Trees less than 30 cm stump diameter were cut with a rubber-tired feller buncher; larger trees were cut by chain saw. Whole trees of all diameters were skidded to the landing outside the watershed by rubber-tired, articulated, skidders. Sawlogs were separated and the remaining stems, tops, and branches were chipped on site. Harvesting was completed in March 1982, and was confined to the dormant season.

METHODS

Sample plots were selected randomly from a 25 X 25-m grid established on the watershed. A stratified, nested design was chosen for sampling of herbaceous and woody plants, including seedlings and sprouts. Seedlings of trees, shrubs, and herbs < 1.3 m tall were inventoried on fifty 1 X 1-m plots by 0.5-m height classes. Seedlings and sprouts taller than 1.3 m from stumps < 10 cm in diameter were measured on sixteen 1 X 25-m transects by 1-cm dbh classes. Sprouts of all heights from stumps ≥ 10 cm in diameter were inventoried on four 25 X 25-m plots. One plot was placed at random on the grid within each of four strata: dry ridge top, midslope westerly aspect, midslope easterly aspect, and poorly drained Leicester soils. The four plots were equal in area to 4% of the watershed.

Inventories of all three types of plots were made in August of 1982, the first growing season, in August of 1984, the third growing season, and in August and November of 1986, the fifth growing season. By mid-August, woody plants had not yet completed the growing season, though many herbs were senescent. Because of the density of the stump sprout clusters at year 5, the 25 X 25-m plots of stumps ≥ 10 cm diameter were inventoried in November after leaf fall.

Biomass of tree seedlings, shrubs, and herbs was estimated by harvesting twenty-one 1 X 1-m plots selected using a ranked-set sampling technique (McIntyre 1952). Biomass of sprouts was estimated by harvesting three stems of each 0.5-m height class for sprouts < 1.3 m tall, and for each 1-cm diameter class for the larger sprouts, by species. The mean oven-dry weight of the three harvested stems for each size and species was then multiplied by the estimated number of stems of that size and species per hectare. Estimates of all size classes were then summed to estimate total biomass per hectare.

Nutrient analyses were performed on each biomass sample collected from the twenty-one 1 X 1-m plots and from each sprout and seedling. Nutrient data were reported as a percent per unit of biomass. The average of the three samples for each species and size class was multiplied by the estimated biomass for that species and size and summed. All samples were dried to a constant weight at 65°C, weighed, and chemically analyzed. The tissues were digested in a Technicon BD-20[2] block digestor. Total Kjeldahl nitrogen was measured on the digested samples with colorimetric analyses performed on the Technicon Autoanalyzer. Cation concentrations of the digested samples were determined by flame atomic absorption spectroscopy (Franson 1975).

RESULTS

Whole-tree clearcutting removed 91% of the aboveground biomass, including some sound dead wood. In the process, all of the trees were cut, and nearly all advance regeneration and shrubs were crushed by the equipment. The vegetative cover quickly reestablished after this treatment. By the end of the first growing season, there were nearly 800,000 living plants ha^{-1} on the area, of which 60% were herbs and shrubs, and 40% were tree seedlings and sprouts (Fig. 1). By the end of the fifth growing season, there were more than one million plants ha^{-1}, of which 90% were herbs and shrubs and only 10% were tree seedlings and sprouts. There was a systematic increase in the total number of stems of all vegetation ha^{-1} over the 5 years, but a consistent decrease in the numbers of stems of tree species. *Betula* represented nearly

---

[2]The use of trade, firm, or corporation names does not constitute an official endorsement or approval by the U.S. Department of Agriculture or the Forest Service of any product or service to the exclusion of others that might be suitable.

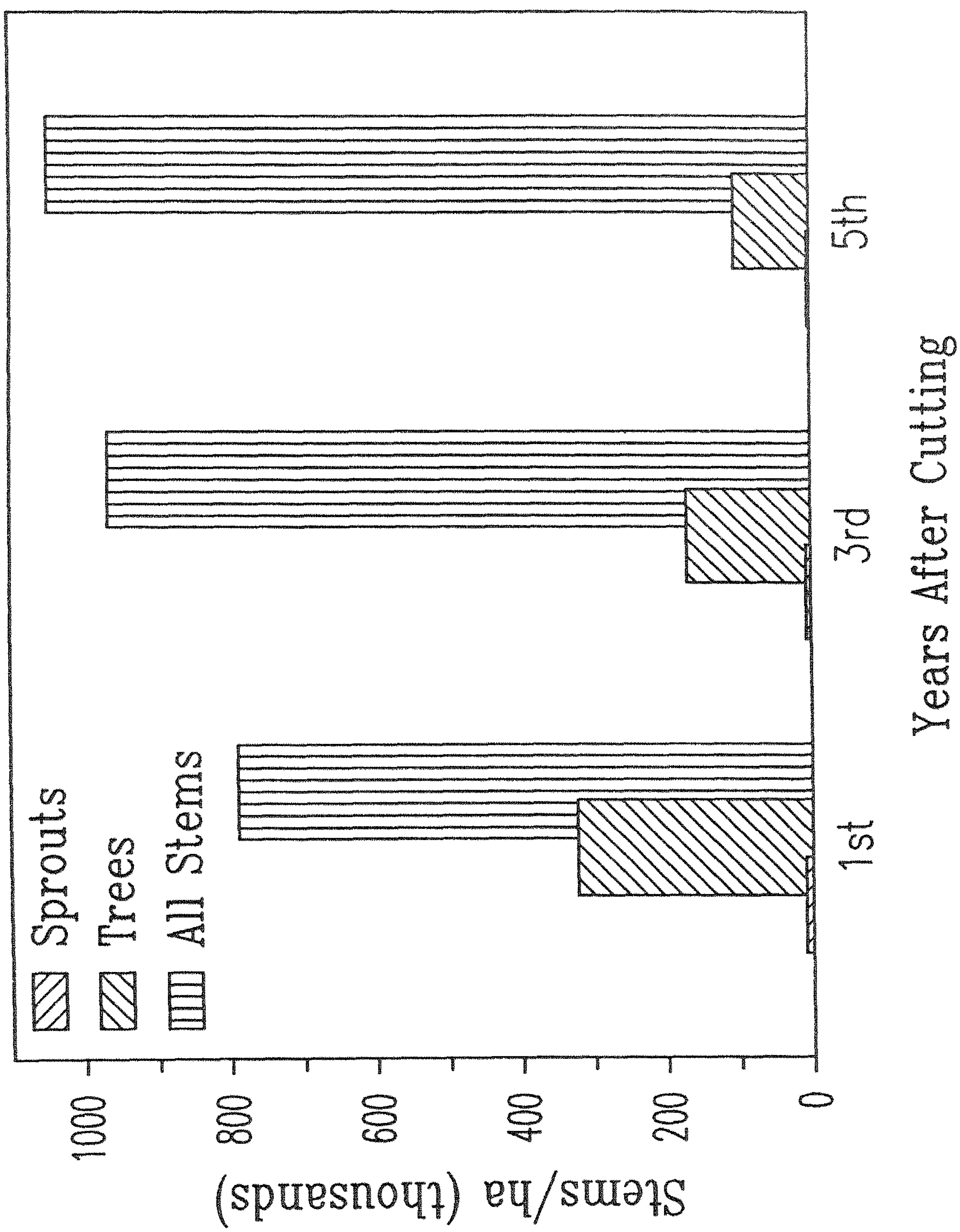

Figure 1. Stems per hectare, in thousands, by year after cutting. The tallest bars include herbs, shrubs, tree seedlings, and sprouts; the bars labeled trees include seedlings and sprouts.

75% of the tree seedlings and sprouts the first year after cutting, and nearly 60% at year 5. *Betula*, *Acer*, *Quercus*, and *Castanea* represented 90% of all the stems of tree seedlings and sprouts on the site the first year after cutting, and 95% in the fifth year.

By the end of the first growing season, plants had produced more than 1,500 kg ha^{-1} of aboveground living biomass. Tree seedlings and sprouts accounted for about 65% of this biomass with herbs and shrubs accounting for the remainder. By the end of the fifth growing season, there were nearly 18,000 kg ha^{-1} of aboveground living biomass on the watershed with tree seedlings and sprouts accounting for more than 70% (Fig. 2). While the number of stems of tree species continued to decline, tree species clearly dominated the site in terms of biomass by year 5. *Acer* accumulated biomass more rapidly than any other genus throughout the 5 years. By year 5, *Acer* accounted for nearly one-third of the biomass of tree species on the site, followed by *Quercus*, *Betula*, and *Castanea*. These four genera comprised nearly 90% of the biomass of tree species at year 5.

By the end of the first growing season, nearly 30 kg ha^{-1} of nitrogen was stored in aboveground living biomass; this increased to more than 130 kg ha^{-1} by the end of the fifth growing season. Trees, including both seedlings and sprouts, accounted for more than 60% of this nitrogen accumulation the first year, and more than 70% by the fifth year (Fig. 3). Aboveground living biomass accumulated nearly 10 kg ha^{-1} of calcium and nearly 20 kg ha^{-1} of potassium the first growing season. Calcium and potassium in the biomass had increased to nearly 80 kg ha^{-1} for both elements by the fifth year, with tree seedlings and sprouts accounting for more than 60% in both cases.

Sprouts from stumps ≥ 10 cm in diameter at time of cutting were a major component of the regeneration on the clearcut watershed. They represented only about 3% of the total numbers of stems of tree species during the first 5 years after cutting (Fig. 1). But they represented 20 to 25% of the biomass of tree species throughout that period (Fig. 2). And by the fifth year after cutting, about 20% of the nitrogen, calcium, and potassium sequestered by tree species, including both seedlings and sprouts, was stored in sprouts from stumps ≥ 10 cm in diameter. These sprouts had accumulated about 13% of the nitrogen, calcium, and potassium stored in all aboveground vegetation on the watershed (Fig. 3).

During the first year after cutting, more than 55% of the sprouts on the watershed were *Quercus*, followed by *Acer*, *Betula*, and *Castanea*. By the fifth year, more than 40% of the sprouts were *Acer*, followed by *Quercus*, *Betula*, and *Castanea* (Fig. 4). Throughout the 5 years, *Quercus* sprouts accumulated the most biomass followed by *Acer* and *Castanea*, with *Betula* a distant fourth (Fig. 5).

At the time of cutting, there were an average of 424 live trees per hectare with stump diameters ≥ 10 cm. By the end of the first growing season, an average of 252 stumps ha^{-1} had sprouted to produce about 9,400 sprouts, an average of 37 live sprouts per live stump. By the end of year 5, an average of 212 stumps ha^{-1} remained alive with about 2,540 live sprouts, an average of 12 live sprouts per live stump.

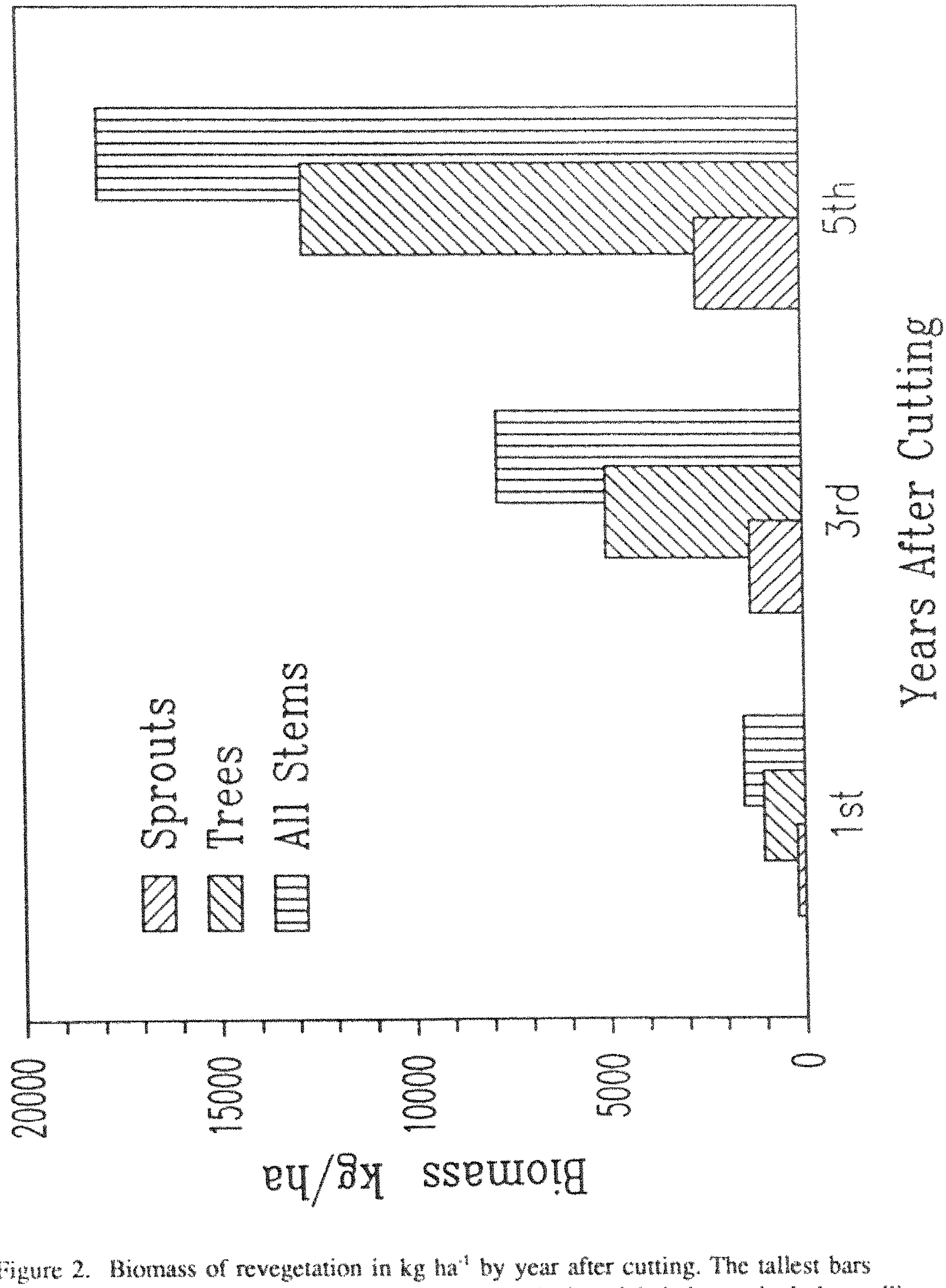

Figure 2. Biomass of revegetation in kg ha^{-1} by year after cutting. The tallest bars include herbs, shrubs, tree seedlings, and sprouts; the bars labeled trees include seedlings and sprouts.

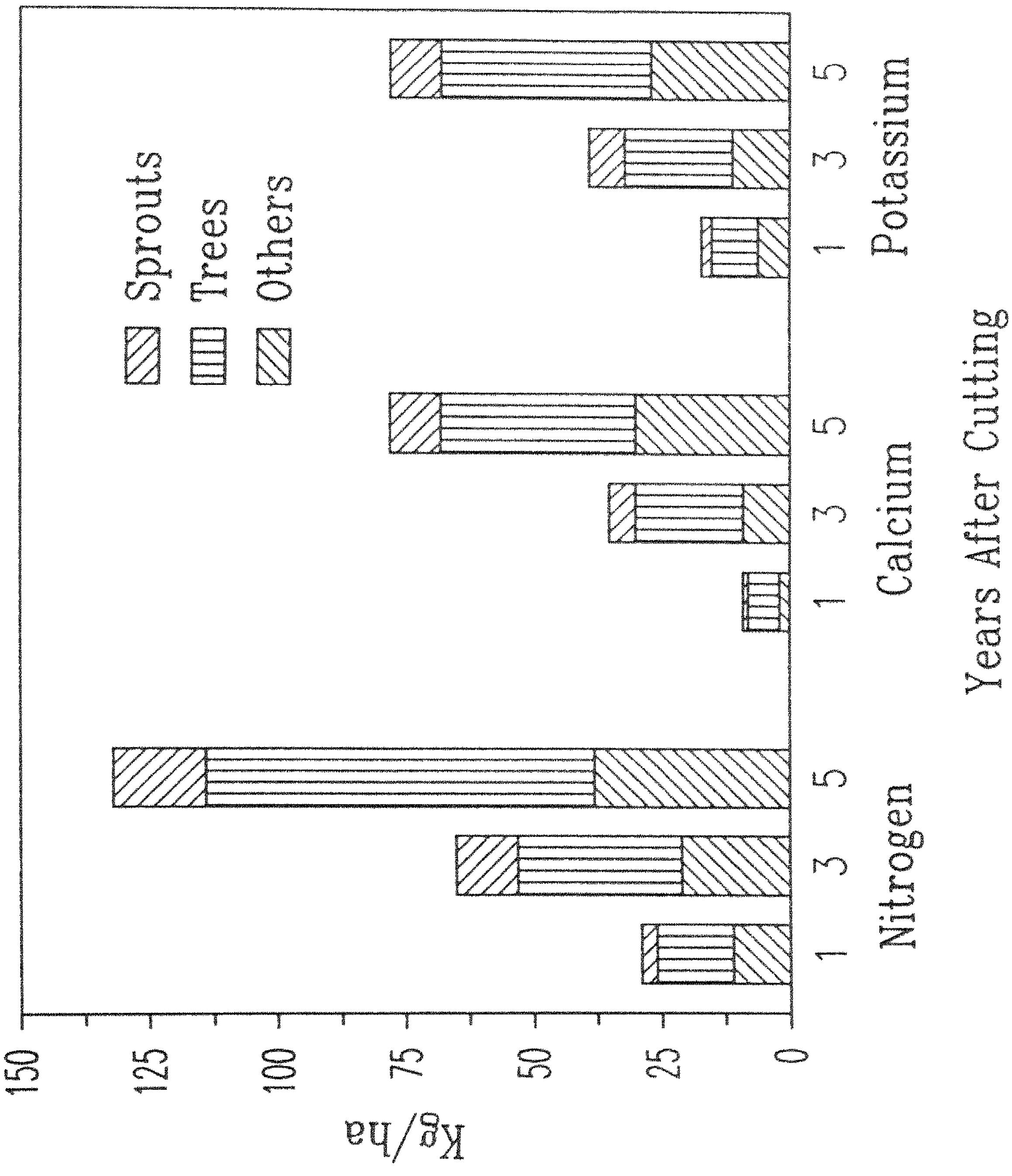

Figure 3. Mass of nutrients accumulated in the aboveground living biomass by years after cutting.

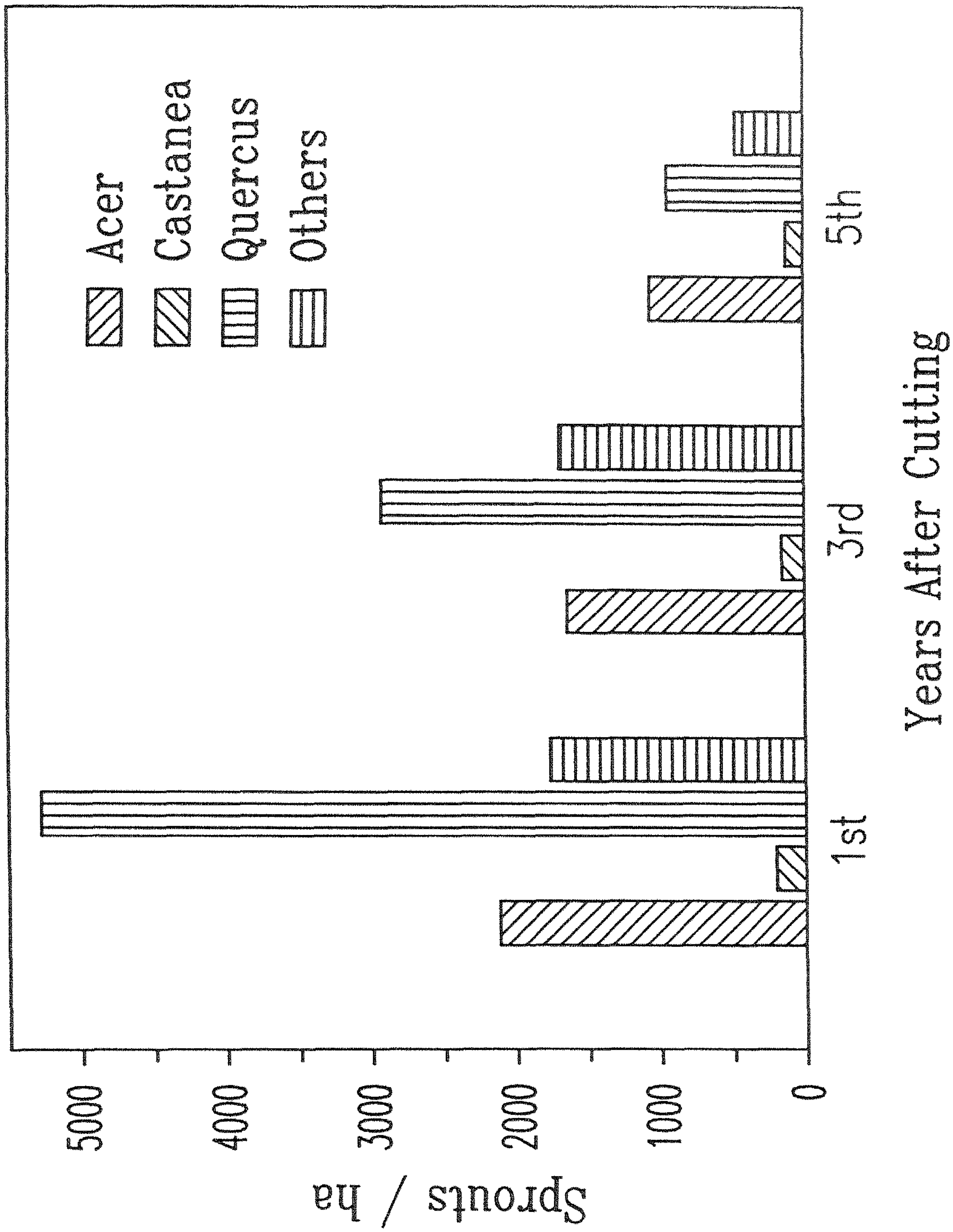

Figure 4. Numbers of sprouts per hectare by species and years after cutting.

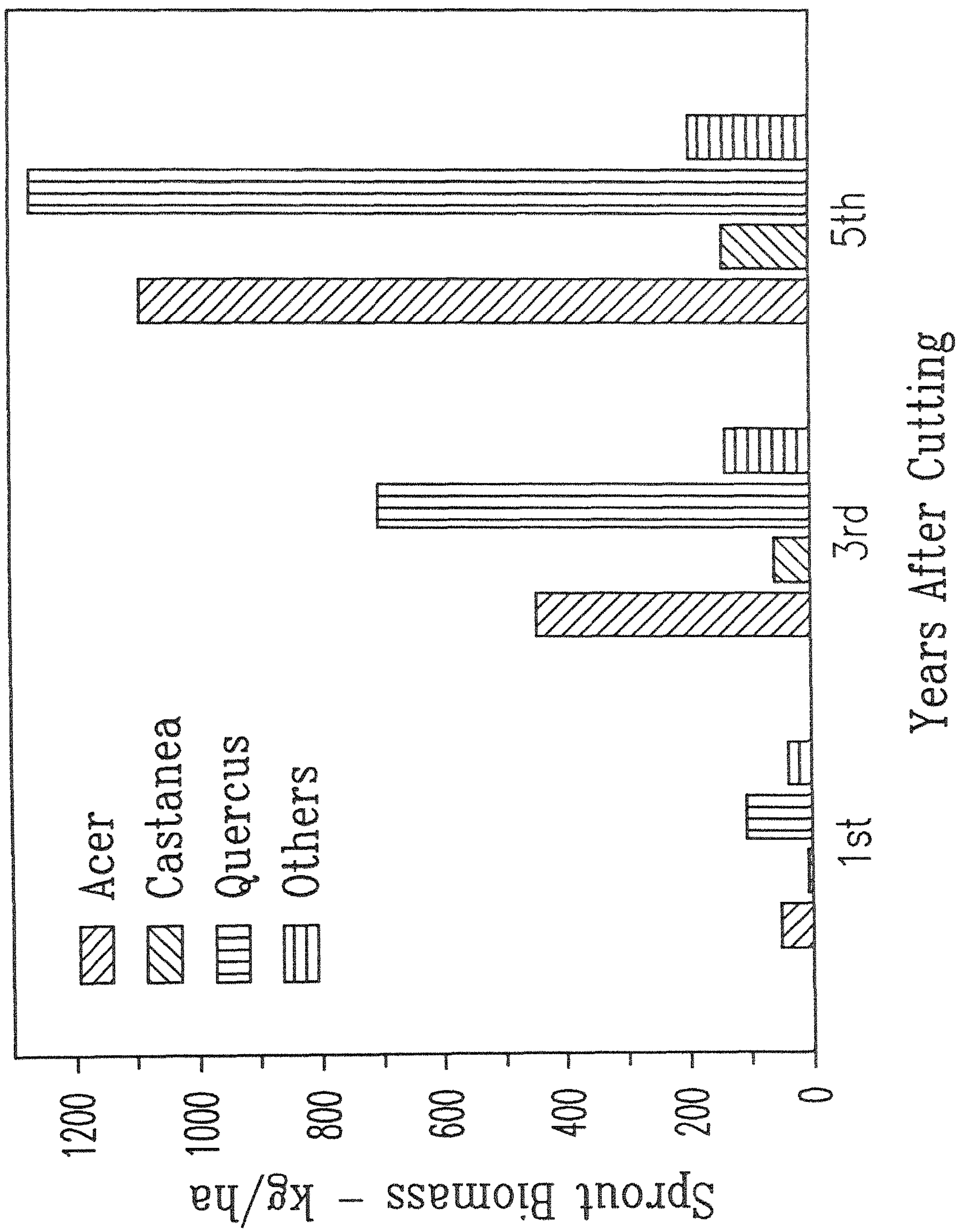

Figure 5. Aboveground living biomass of sprouts per hectare by species and years after cutting.

More than 80% of the *Acer* stumps on the four sample plots sprouted the first year after cutting, and all continued to have live sprouts throughout the 5 years. About 75% of the *Quercus* stumps sprouted but that percentage dropped to about 60% by year 5. Only about 25% of the *Betula* stumps sprouted (Table 1).

Table 1.--Number of live stumps by genus on the four 25 x 25 m sample plots.

	Years after cutting		
Genus	0	1	5
Acer	12	10	10
Betula	35	9	8
Quercus	37	28	22
Others	22	16	13

Of all the genera, *Acer* produced the most sprouts per stump and retained the greatest number of live sprouts over the 5 years. Approximately 50% of the *Acer* sprouts and 75% of the *Quercus* sprouts died over the 5-year period. (Table 2).

Table 2.--Average number of sprouts per live stump by genus. (Standard errors).

	Years after cutting	
Genus	1	5
Acer	53 (7)	26 (6)
Betula	21 (9)	4 (2)
Quercus	47 (8)	11 (1)
Others	19 (6)	9 (3)

DISCUSSION

The importance of sprouts in a regenerating forest can be evaluated in terms of biomass, density, and species represented. Density is an indicator of stand age and structure; biomass reflects dominance; species indicates future worth. Together, we used these three variables to characterize revegetation on our study area.

Sprouts as a Component of Regeneration

Beginning with the first growing season after cutting, tree seedlings and sprouts had the greatest amount of aboveground living biomass on the site. Stump sprouts represented 19% of that biomass and, on average, accumulated 10 times more biomass than seedlings. However, sprouts accounted for only 3% of the total stems of tree species on the site. Other studies have reported larger numbers of sprouts than were tallied in our study. Boring et al. (1981) found that both density and biomass of sprouts exceeded density and biomass of tree seedlings following cable logging of a watershed in North Carolina. Mann (1984) reported that sprouts dominated whole-tree and saw-log clearcut sites in Tennessee, both in terms of numbers of stems of tree species and biomass.

Betula seedlings and sprouts far exceeded the total number of seedlings and sprouts for other genera of tree species in the first growing season. Initially, scarified soil conditions following whole-tree harvest probably favored the establishment of *Betula* seedlings. Although the total numbers of *Quercus* stems were less than either *Betula* or *Acer*, a far greater proportion (72%) of *Quercus* stems were sprouts. In addition, almost all (97%) *Quercus* biomass was in sprouts, compared with 16% for Acer and 4% for *Betula*. Thus, sprouts were a more important form of regeneration for *Quercus* than for other genera in the first growing season.

Dynamics of Sprouts over the First Five Years

Sprouts continued to account for a small proportion of the total numbers of stems per hectare of all plants over the 5 years studied (Fig. 1). Whereas the total number of plant stems increased, both the total number of stems of all tree species and the total number of sprouts decreased. These data suggest that initiation of sprouts occurred largely in the first (and second) growing season after harvest. Roth and Hepting (1943) reported that there was rarely further sprouting of oaks beyond the second year after cutting.

By contrast, herbaceous plants and tree seedlings apparently continued to fill in open spaces on the forest floor for several years after cutting. Skid trails and other severely disturbed areas may take several years to stabilize before plants can become established. Light and moisture conditions at the soil surface are rapidly changing at this time (Bormann and Likens 1979), resulting in changes in species dominance (Hornbeck et al. 1987). Our study suggests that although species dominance may shift, the tree species present in the first and fifth growing seasons will be the components of the future forest, as discussed by Martin et al. (1987).

It is not possible to predict the long-term survival of sprouts with certainty. At our site, more than three quarters of the *Quercus* sprouts had died by the fifth year. McIntyre (1936) reported that mortality of oak sprouts continued to be high during the first 10 years following cutting but slowed thereafter. McIntyre also found that the basal area of sprouts decreased with stand age. Therefore, clearcut sites may be characterized by dominant, rapidly growing sprouts only in the first one or two decades after clearcutting.

Although we did not carry out a systematic study of causes of sprout mortality, we found evidence of several diseases which probably contributed to mortality. Fruiting bodies of *Armillaria* spp. were observed on numerous stumps over the entire site. This root disease reduces not only sprouting capability of stumps but also sprout survival (P.M. Wargo, USDA For. Serv. pers. comm.). By the fifth year, some of the largest sprouts apparently were too heavy to be supported by the thin living cambial layer of the stump, and whole clusters of these sprouts peeled away from the stump, fell over, and died. *Castanea*, which had been a very minor component of the precut forest, demonstrated extensive sprouting after harvest. These sprouts grew rapidly in diameter and height and rapidly accumulated biomass. But by year 5, the majority of sprouts showed evidence of chestnut blight (*Cryphonectria parasitica* (Murr.) Barr) and died.

Quercus stumps sprouted quickly and prolifically, accounting for nearly twice as much biomass as the other species in the first growing season and retaining that dominance through year 5. However, *Acer* accumulated biomass more slowly but nearly equalled *Quercus* by the fifth year. Mroz et al. (1985) similarly found that red maple biomass accumulated slowly during the first 3 years after cutting and then increased dramatically in the fourth year.

Sprouts Relative to Precut Forest

Prior to harvest, *Acer* was the most numerous tree genus and *Quercus* accounted for the most biomass at the Connecticut site (Martin et al. 1987). Since Mann (1984) found a greater average number of sprouts per live stump for red maple than for oak in Tennessee, we expected *Acer* to dominate the site immediately. However, this was not the case, and there was no clear relationship between species and sprouting at the Connecticut site. Nor was there an obvious effect of stump diameter on sprouting. Roth and Hepting (1943) showed that for *Quercus*, sprout initiation increases up to a stump diameter of around 12 inches (30 cm) and then decreases. Dominant *Quercus* trees on the Connecticut site were 80 to 100 years old and averaged 20 to 30 cm dbh. Allowing for the difference between dbh and stump diameter, these trees fell well within the range of stump diameters capable of producing large numbers of sprouts. However, approximately half of all stumps ≥ 10 cm at the Connecticut site failed to sprout.

Intensive use of mechanized equipment may partially explain the small percentage of stumps sprouting and the small number of sprouts measured in Connecticut relative to findings from studies by Mann (1984) and Boring et al. (1981). Mann (1984) found a lower number of sprouts on a whole-tree-harvested site compared with a sawlog-harvested site. She reported that skidding of whole trees tended to increase mechanical damage to stumps and soil, and removal of nonmerchantable residues reduced protection of soil surface and stumps afforded by leaving these materials in conventional harvests. Miller and Phillips (1984) demonstrated that shearing by fellers damaged stumps and resulted in lower numbers of sprouts. Whole-tree harvesting disturbed approximately 70% of the soil surface of our site in Connecticut (Martin 1988). Although we did not assess associated damage to stumps, we observed that shearing tended to shatter stumps, especially birch. It is likely that mechanical harvesting reduced the number of stumps that sprouted as well as the number of sprouts per stump to some degree. Site quality is another factor that may have influenced sprouting. Mroz et al. (1985) concluded that sprout numbers for northern hardwoods were independent of site quality, but similar studies have not been reported for central hardwoods.

Importance of Sprouts in Conserving Nutrients

One of the major concerns with clearcutting in general and with whole-tree clearcutting in particular is the potential for a substantial loss of nutrients from the site both by the removal of wood products and leaching losses. Rapid revegetation of the site will reduce these losses in several ways (Bormann and Likens 1979, Hornbeck 1986). The first is by the sequestering of available nutrients from the soil into long-term storage in aboveground biomass. The second is by covering the watershed with vegetation which shades the site, increases transpiration, slows the velocity of raindrops which reduces erosion and increases infiltration, and works toward restoring the microclimate of the site. Sprouts play a major role in both processes since they have rapid initial growth rates.

Throughout the first 5 years after cutting at our site, sprouts stored about 13% (11 to 18%) of the nitrogen, calcium, and potassium accumulated on the watershed by all aboveground living biomass, and about 20% of those elements stored in tree species. The first year after cutting, this represented 1 to 3 kg ha^{-1}, but by year 5 had increased to 10 kg ha^{-1} of potassium and calcium and 18 kg ha^{-1} of nitrogen. These fifth-year values represented 6% of the nitrogen stored in aboveground living biomass of the precutting forest, 2% of the precutting calcium, and 6% of the precutting potassium.

Boring et al. (1981) reported biomass from a 1-year-old clearcut in the southern Appalachians that was similar to ours. They reported 1,725 kg ha^{-1} to our 1,540 kg ha^{-1} for all living biomass. Accumulations of nitrogen and potassium were similar on both sites, but nearly twice the calcium accumulated at the North Carolina site. However, they reported 63% of their biomass was sprout biomass, with 57% of the nitrogen, 35% of the potassium, and 61% of the calcium occurring in sprouts.

The southern Appalachian site may represent one extreme in the amounts of nutrients that may be sequestered by 1-year-old biomass because of the lack of soil disturbance and stump damage and the longer growing season of North Carolina. Our site may represent the other extreme due to the more northern climate and the severe site disturbance and stump damage caused by mechanical whole-tree clearcutting.

SUMMARY

1. Stump sprouts are an important component in the revegetation of a central hardwood forest after whole-tree clearcutting. They are especially important in the early stages of forest development. They play an important role initially in reestablishing the microclimate of the site; then they play a transitional role in forest development. However, stump sprouts alone may not regenerate a viable forest.

2. Competitive thinning and root diseases change the dynamics of the sprout population too rapidly to predict, at year 5, whether trees of sprout origin will be a major component of the future forest.

3. Revegetation of all types, including herbs, shrubs, and tree seedlings and sprouts, play a vital role in conserving nutrient elements on the site.

4. Whole-tree clearcutting does not seem to have radically changed the species composition of the site. The composition of the regeneration on the whole-tree clearcut is similar to that of the preharvest forest. Before cutting, *Acer* was the most common genus followed by *Quercus* and *Betula*. At year 5, *Betula* is the most common, followed by *Acer* and *Quercus*. Prior to harvesting, *Quercus* contained the most biomass, followed by *Betula* and *Acer*. At year 5, *Acer* had accumulated the most biomass, followed by *Quercus* and *Betula*.

5. *Quercus* is the most commercially valuable genus in the region. Therefore, forest managers are likely to encourage oak regeneration in this region. If so, it is important for them to consider the sprouting potential of the site before cutting, including:

a. species,
b. stump diameters,
c. season of cutting,
d. stump- and root-disease potential,
e. soil-disturbance potential,
f. stump damage during logging.

LITERATURE CITED

Boring, L.R., C.D. Monk, and W.T. Swank. 1981. Early regeneration of a clear-cut southern Appalachian forest. Ecology 62:1244-1253.

Bormann, F.H., and G.E. Likens. 1979. Pattern and process in a forested ecosystem. Springer-Verlag, New York. 253 p.

Franson, M.A. (ed.). 1975. Standard methods for the examination of water and wastewater. 14th ed. Am. Public Health Assoc., Washington, DC 1193 p.

Hornbeck, J.W. 1986. Nutrient cycles and forest productivity. In: Smith, C.T., C.W. Martin, and L.M. Tritton (eds.). Proc. of the 1986 Symposium on the Productivity of Northern Forests Following Biomass Harvesting, 1-2 May 1986. University of New Hampshire, Durham. USDA For. Serv. Gen. Tech. Rep. NE-115. p. 23-27.

Hornbeck, J.W., C.W. Martin, R.S. Pierce, F.H. Bormann, G.E. Likens, and J.S. Eaton. 1987. The northern hardwood forest ecosystem: Ten years of recovery from clearcutting. USDA For. Serv. Res. Paper NE-596. 30 p.

Hornbeck, J.W., C.T. Smith, C.W. Martin, L.M. Tritton, and R.S. Pierce. 1990. Effects of intensive harvesting on nutrient capitals of three forest types in New England. For. Ecol. Manage. 30:55-64.

Johnson, P.S. 1977. Predicting oak stump sprouting and sprout development in the Missouri Ozarks. USDA For. Serv. Res. Pap. NC-149. 11 p.

Jones, R.H., and D.J. Raynal. 1987. Root sprouting in American beech: production, survival, and the effect of parent tree vigor. Can. J. For. Res. 17:539-544.

Mann, L.K. 1984. First-year regeneration in upland hardwoods after two levels of residue removal. Can. J. For. Res. 14:336-342.

Martin, C.W. 1988. Soil disturbance by logging in New England--review and management recommendations. North. J. Appl. For. 5:30-34.

Martin, C.W., L.M. Tritton, and J.W. Hornbeck. 1987. Revegetation after whole-tree clearcutting of hardwoods in Connecticut. In: R.L. Hay, F.W. Woods, and H. DeSelm (eds.) Proc., Central Hardwood Forest Conference VI, 24-26 February 1987. Univ. of Tennessee. Knoxville. p. 119-126.

McIntyre, A.C. 1936. Sprout groups and their relation to the oak forests of Pennsylvania. J. For. 32:1054-1058.

McIntyre, G.A. 1952. A method for unbiased selective sampling using ranked sets. Aust. J. Agric. Res. 3:385-390.

Miller, A.S., and D.R. Phillips. 1984. Chainsaw and shear cutting of upland hardwoods: Impact on regeneration.Georgia For. Comm. For. Res. Pap. 53. p. 4-11.

Mroz, G.D., D.J. Frederick, and M.F. Jurgensen. 1985. Site and fertilizer effects on northern hardwood stump sprouting. Can. J. For. Res. 15:535-543.

Roth, E.R., and G.H. Hepting. 1943. Origin and development of oak stump sprouts as affecting their likelihood to decay. J. For. 41:27-36.

Smith, D.M. 1986. The practice of silviculture. 8th ed. John Wiley & Sons, New York. 527 p.

Solomon, D.S., and B.M. Blum. 1967. Stump sprouting of four northern hardwoods. USDA For. Serv. Res. Pap. NE-59. 13 p.

Stephens, G.R., and P.E. Waggoner. 1980. A half century of natural transitions in mixed hardwood forests. Connecticut Agric. Exp. Stn. Bull. 783. 43 p.

Tritton, L.M., C.W. Martin, J.W. Hornbeck, and R.S. Pierce. 1987. Biomass and nutrient removals from commercial thinning and whole-tree clearcutting of central hardwoods. Environ. Manage. 11:659-666.

Tritton, L.M., C.W. Martin, J.W. Hornbeck, R.S. Pierce, and C.A. Federer. 1982. Organic matter and nitrogen content of a central hardwood forest in Connecticut. In: R.N. Muller (ed.) Proc., Central Hardwood Forest Conf. IV, Univ. of Kentucky, Lexington. p. 271-284.

U.S. Department of Agriculture, Soil Conservation Service. 1981. Soil survey of the Cockaponset State Forest research project area, Chester, CT. USDA Soil Conserv. Serv., Storrs, CT.

Wendel, G.W. 1975. Stump sprout growth and quality of several Appalachian hardwood species after clearcutting. USDA For. Serv. Res. Pap. NE-329. 9 p.

PLANTING STOCK TYPE X GENOTYPE INTERACTIONS AFFECT EARLY OUTPLANTING PERFORMANCE OF BLACK WALNUT SEEDLINGS

J. W. Van Sambeek, James W. Hanover, and Robert D. Williams[1]

Abstract: A provenance/progeny test was established in south central Indiana with seedlings from 72 open-pollinated families from across the commercial range of black walnut (*Juglans nigra* L.). The seedlings were grown in a conventional hardwood nursery and in containers in a greenhouse. Seedlings were outplanted in 1981 on an old-field site in Johnson County using a split plot design with families randomly assigned within planting stock type. Survival after three growing seasons averaged 95% across all families and planting stock type. A planting stock type x genotype interaction existed for height growth for the first 2 years after establishment. Both nursery-grown and container-grown seedlings showed varying amounts of dieback during the first growing season. After the second growing season, the container-grown stock has initiated positive height growth while the nursery-grown seedlings continued to die back. Three years after establishment, effects of genotype and planting stock type had dissipated and effects of seed collection zone (provenance) were still not present. Results with container-grown seedlings are consistent with other studies using nursery-grown seedlings and show that effects of genotype and site account for increasingly more of the tree growth variation as the planting gets older.

INTRODUCTION

Nursery-grown seedlings of black walnut (*Juglans nigra* L.) characteristically have a long taproot with few lateral roots to serve as future sites for new root initiation. In addition, the taproot on nursery-grown seedlings is frequently cut during lifting or planting, thus altering the shoot-to-root balance which may also contribute to transplant shock. Because container-grown seedlings usually have a well-developed fibrous root system, they have many more sites for initiating new roots following outplanting. Past research has shown that

---

[1]Supervisory Research Plant Physiologist, USDA Forest Service, North Central Forest Experiment Station, Forestry Sciences Laboratory, Carbondale, IL 62901; Professor, Department of Forestry, Michigan State University, East Lansing, MI 48824; and Research Forester (Retired), USDA Forest Service, North Central Forest Experiment Station, Bedford, IN 47421.

The authors wish to acknowledge the cooperation of the Indiana Department of Natural Resources staffs at the Vallonia Tree Nursery and at the Atterbury State Fish and Wildlife Area.

seedlings grown in containers initiate height growth sooner than bare-root seedlings from nursery beds (Van Sambeek et al. 1987, von Althen 1986).

The effects of genotype and/or provenance (geographical source) on early field performance of nursery-grown seedlings are well documented (Bey 1979; Rink 1984, Rink and Van Sambeek 1987); however, similar studies with container-grown seedlings have not been done. The extent to which planting stock type and genotype may interact with seedling growth following outplanting is unknown for black walnut seedlings. Therefore, we established a study in 1980 to determine the extent to which growth interactions occur among nursery-grown and container-grown seedling from the same open-pollinated families from across the commercial range of black walnut.

MATERIALS AND METHODS

In the fall of 1979, seed from 250 single-tree or stand collections from 14 provenances (seed collection zones) were collected, assigned accession or family numbers, and cleaned. Collections were limited essentially to the commercial range of black walnut (Funk 1978). Half of the seed from each collection with more than 300 sound seed were sown by seedlot in single plots at the Vallonia Tree Nursery near Brownstown, Indiana, in December of 1979. Seedlings were lifted in November and December of 1980. A random sample of 32 seedlings from each seedlot was measured for basal diameter (3 cm above the root collar), root and shoot length, and an index (0 to 2) of root fibrosity (0 = less than three lateral roots per cm of taproot, 1 = three to five lateral roots per cm of taproot, 2 = six or more lateral roots per cm of taproot). For each seedlot, seedlings were randomly divided into bundles of four seedlings each with one seedling labelled with the seedlot number. Four bundles of four seedlings for each seedlot were packaged in kraft paper for overwinter storage at 4° C for each planting to be established.

In June 1980, germinating seed from each seedlot were sown in 6- x 6- x 30-cm polyethylene-coated paperboard plant bands in a Michigan State University greenhouse and grown according to the techniques described by Wood and Hanover (1981). Briefly, seedlings were grown in RediEarth, a commercial peat-vermiculite soil mix, under continuous fluorescent light and carbon dioxide enrichment for approximately 4 months. Seedlings were hardened-off for approximately 3 months before being removed from the containers for packaging and overwinter storage. For each collection, 16 seedlings were randomly divided into four bundles of four seedlings each with one seedling from each bundle labelled with seedlot number. Labelled bundles were packaged in kraft paper for cold storage and shipping to the Indiana planting site in late March.

Container-grown and nursery-grown seedlings were both slit-planted using the MICHOTIP hardwood tree planter on March 25, 1981. Nursery-grown seedlings with excessive lateral roots or taproots over 25 cm long were root pruned before planting. Seedlings were planted on an open, grass-covered old field in the Atterbury State Fish and Wildlife Area located in Johnson County, Indiana. Soils are primarily poorly- to moderately-well drained Crosby (fine, mixed, mesic, Aeric Ochraqualfs) and Miami (fine-loamy, mixed, mesic, Typic Hapludalfs) silt loams. Seedlings were planted in 4-tree row plots at a nominal spacing of 2.0 m within rows and 3.0 m between rows using a split plot design for planting stock type with individual seedlots randomly arranged within each planting stock type.

The planting site was sprayed in the fall of 1980 with glyphosate (2.5 l ai per ha) using 1-m wide bands at 3-m intervals. Immediately after seedlings were outplanted, all rows were strip-sprayed with simazine (4.5 kg ai per ha). There was no additional weed control in subsequent years to control competition from the grass sod. Climatological data for 1980 to 1983 for central Indiana were obtained from records published by the National Oceanic and Atmospheric Administration.

Survival, live height, and basal diameter (3 cm above soil line) were recorded at outplanting and annually after each growing season for 3 years. Means for height, basal diameter, and net growth for all live trees were determined for each four tree plot. For this report, only data from 72 open-pollinated families (single-tree collections) that had both nursery-grown and container-grown seedlings and were replicated across all four blocks were analyzed. Families were assigned to provenances according to the preliminary seed collection zones identified for black walnut in 1980 (Deneke et al. 1987). Variation was analyzed as a split-plot experiment using plot means to determine if differences ($p < 0.05$) existed among planting stock type and/or genotype or if an interaction was present. Pearson correlation analyses were used to generate correlation matrices on a family mean basis.

RESULTS

Analysis by Family Means

Survival for both the nursery-grown and the container-grown seedlings has been excellent on this questionable site for black walnut. After the first growing season, survival for the nursery-grown seedlings averaged 98.9% with the container-grown seedlings averaging 97.4%. After three growing seasons, survival for the nursery-grown seedlings averaged 95.7% compared to 96.2% for the container-grown seedlings (Table 1). Survival among the families after three growing seasons ranged from 81% for family 189 from Bell County, Kentucky, to 100% for 21 of the 72 families. Overall, there were no statistically significant differences for survival among families or planting stock type.

A highly significant interaction for height growth existed among planting stock types x genotype during the first two years after outplanting which disappeared after the third growing season (Table 2). Many of the walnut seedlings showed substantial dieback after the first growing season; however, because of the interaction there was no consistent genotypic response among families outplanted as nursery- and container-grown planting stock. For example, dieback on nursery-grown seedlings for family 295 from Alexander County, Illinois, averaged 30.9 cm compared to 15.2 cm for the container-grown seedlings. Conversely,

Table 1.--Third year survival, annual net height growth, and root fibrosity index for nursery-grown and container-grown black walnut seedlings by family and seed collection zone.

Seed Coll. Zone[1]	Family number[2]	Location State	Location County	Third Year Survival Nurs.	Third Year Survival Cont.	Net annual height growth First year Nurs.	First year Cont.	Second year Nurs.	Second year Cont.	Root Fibr. Index[3]
				--- % ---		----------- cm ---------				
2	328	IA	Cedar	94	100	- 8.5	- 4.6	- 4.7	1.5	0.50
	329	IA	Clayton	100	4	- 2.1	-10.1	- 0.7	6.3	0.47
	330	IA	Taylor	100	100	0.9	- 7.9	- 6.4	7.1	0.22
	333	IA	Marshall	100	81	- 0.8	-10.9	-17.1	5.2	0.16
	336	IA	Jefferson	100	94	- 3.9	- 7.0	- 3.8	8.0	0.28
	339	IA	Taylor	100	94	- 2.3	-13.0	- 8.9	- 3.9	0.16
	340	IA	Marshall	94	94	- 5.6	-14.5	- 0.1	4.8	0.13
Seed Collection Zone Means				98	94	- 3.3	- 9.7	- 6.0	4.1	0.27
3	297	IL	Fulton	94	94	7.3	- 9.6	-12.3	- 6.1	NA
	298	IL	Warren	100	100	- 1.0	- 1.2	4.0	7.9	0.44
	299	IL	Henry	100	100	6.3	- 1.4	- 5.9	7.4	0.88
	300	IL	Carroll	100	100	0.5	- 4.2	-14.6	8.5	0.66
Seed Collection Zone Means				98	98	3.3	- 4.1	- 7.2	4.4	0.66
4	127	MI	Allegan	100	100	- 7.2	5.9	- 1.0	1.2	0.88
	131	MI	Berrien	100	92	- 5.8	- 6.0	- 8.7	1.1	0.00
	134*	MI	St. Joseph	94	88	- 1.6	- 4.4	- 4.0	3.4	0.13
	139	MI	Branch	94	94	-10.4	-16.6	- 1.4	0.1	0.28
	143*	MI	Eaton	100	81	- 2.4	- 5.2	2.1	8.9	0.50
	146*	MI	Jackson	88	100	-12.0	- 6.2	0.7	1.8	0.00
	147	*MI	Jackson	100	100	- 7.2	-13.0	-15.9	0.8	0.13
	212	ON	Middlesex	100	100	1.8	- 6.3	0.6	6.4	0.84
	215	ON	Brantford	94	94	- 2.9	- 8.1	- 3.8	1.5	0.56
	218	NY	Chautauqua	100	94	-15.4	- 4.7	- 8.0	1.7	0.56
	222	OH	Huron	94	100	3.4	0.6	4.3	2.2	0.25
	247	MI	Igham	100	100	- 8.8	- 1.0	- 7.3	3.5	0.16
Seed Collection Zone Means				97	95	- 5.7	- 6.4	- 3.5	2.7	0.36
6	345	MO	Adair	100	100	- 9.0	- 1.4	- 4.9	8.2	0.13
	354	MO	Pike	94	100	- 6.7	- 9.0	-13.1	- 0.1	0.13
	384	IL	Macon	100	88	- 6.4	-10.5	-15.1	6.5	0.25
	386	IL	Macon	100	100	- 1.9	- 1.8	-16.5	13.9	0.31
Seed Collection Zone Means				97	97	- 6.0	- 5.7	-14.9	7.2	0.20

7	261	IN	Owen	100	100	- 5.6	- 0.1	- 3.1	-11.2	0.09
	264	IN	Putnam	100	100	- 0.1	- 7.0	-11.2	0.6	1.19
	266	IN	Bartholomew	94	100	- 4.4	-16.1	-21.6	4.6	1.00
	274	IN	Lawrence	100	100	- 5.9	-20.7	-27.9	5.3	0.97
	277	IN	Lawrence	94	94	-13.9	- 1.9	- 8.3	1.8	0.72
	286	IN	Lawrence	94	100	7.0	- 3.6	2.9	12.0	1.22
Seed Collection Zone Means				97	99	- 3.1	- 9.2	-13.0	3.5	0.86
10	174	KY	Hancock	100	100	- 4.9	- 5.2	-16.5	5.2	0.19
	202	KY	Ohio	100	94	- 7.1	-14.4	- 2.1	- 4.2	0.66
	295	IL	Alexandria	69	100	-30.9	- 7.7	-15.2	6.9	0.00
	296	IL	Hardin	94	94	- 3.8	- 4.0	-17.5	6.0	1.00
	341	MO	Texas	100	94	-18.7	- 3.4	- 7.6	3.7	0.50
	348	MO	Perry	88	88	-17.1	-15.3	- 8.7	3.4	0.38
	380	IL	Jackson	94	100	-21.6	- 6.6	- 2.7	6.1	0.19
	381	IL	Randolph	100	88	- 3.3	- 1.3	-11.4	10.4	0.88
	382	IL	Williamson	88	100	-15.8	- 5.5	-24.8	8.9	0.19
Seed Collection Zone Means				92	95	-13.7	- 7.0	-11.8	5.2	0.44
11	158	KY	Hardin	100	100	- 0.9	-14.1	-11.9	8.3	0.50
	172	KY	Boyd	94	94	- 4.9	- 5.2	- 3.0	9.2	0.50
	194	KY	Barrier	100	100	- 2.7	-14.4	-11.9	- 0.1	1.19
	203	KY	Wolfe	94	100	- 5.2	-11.9	-16.6	6.4	0.66
	207	KY	Washington	100	100	- 2.2	- 5.9	- 6.1	2.3	0.75
	233	WV	Tucker	100	100	3.4	-13.1	0.1	3.2	0.75
	242	WV	Tyler	94	94	2.5	- 4.8	- 5.1	3.4	0.47
	244	WV	Mason	94	94	4.7	- 1.7	1.9	4.3	0.41
	320	WV	Harrison	100	100	4.2	- 7.1	- 4.4	0.8	0.22
Seed Collection Zone Means				97	98	- 0.1	- 8.7	- 6.3	4.2	0.60
13	342	MO	Ripley	94	100	-11.8	-22.6	-25.8	8.0	0.53
	356	MO	Pulaski	100	81	0.3	- 7.4	-13.3	2.6	0.56
	357	MO	Oregon	100	94	-10.6	-13.5	-22.5	3.1	0.28
Seed Collection Zone Means				98	92	- 7.4	-14.5	-20.5	4.6	0.46
14	253	TN	Macon	88	100	0.2	- 3.2	- 0.6	7.6	0.31
	254	TN	Macon	100	94	- 1.6	- 4.7	- 6.2	7.2	0.34
	369	TN	Smith	94	100	- 6.1	- 8.8	-17.4	- 1.4	0.28
Seed Collection Zone Means				94	98	- 2.5	- 5.6	- 8.1	4.5	0.31
15	180	KY	McCreary	94	94	- 6.6	- 4.1	-15.0	3.8	0.06
	189	KY	Bell	69	94	-10.7	- 7.5	- 1.4	1.7	0.09
	192	KY	Clay	94	94	- 5.4	-11.5	- 9.9	3.6	0.50
	225	WV	Greenbriar	100	94	3.6	-10.2	0.9	12.5	0.53
	228	WV	Rock Bridge	94	94	- 7.0	-16.0	- 2.3	8.5	1.19
	229	WV	Rogne	88	100	-14.1	- 9.1	-10.8	3.1	0.38

	236	WV	Mercer	88	94	1.4	- 4.9	- 0.5	5.5	0.69
	246	WV	Wyoming	81	100	- 4.6	-14.6	- 9.9	3.7	0.59
Seed Collection Zone Means				88	96	- 5.4	- 9.7	- 6.1	5.3	0.50
16	149	TN	Anderson	94	100	- 4.5	-19.7	- 7.9	10.2	0.84
	360	TN	Lincoln	100	100	- 1.6	- 9.6	- 9.2	0.9	0.50
	363	TN	Washington	94	94	- 1.0	-11.0	-35.9	1.6	0.69
	366	TN	Warren	94	100	- 5.2	-10.8	-18.1	7.9	0.22
	372	TN	Overton	100	94	2.6	-16.6	- 1.4	- 1.8	0.97
	374	TN	White	100	100	1.9	- 3.6	-16.6	3.4	1.03
	376	TN	Knox	100	100	- 2.0	- 3.1	- 6.1	2.4	1.19
Seed Collection Zone Means				98	97	- 1.4	-10.6	-13.6	3.5	0.78

[1]Provenance is based on the preliminary seed collection zones for black walnut identified by Deneke et al. (1987).
[2]Family number can be converted to the North Central Forest Experiment Station Accession Number or the MICHOTIP Accession Number by adding 10,200 or 47,350,000, respectively. An * indicates seed was collected from an above average tree in a small black walnut planting.
[3]Root Fibrosity Index ranges from 0 for seedlings with less than 3 lateral roots per cm of taproot to 2.00 for seedlings with 6 or more lateral roots per cm of taproot.

Table 2.--Analyses of variance for seedling height and basal diameter growth from 72 families grown as both nursery- or container-grown planting stock.

Source of variation	Degrees of freedom	Height growth			Basal diameter growth		
		Year 1	Year 2	Year 3	Year 1	Year 2	Year 3
		- - - - - - - - - - - - - - mean sum of squares[1] - - - - - - - - - - - - -					
Stock type	1	1,953	25,120	834	22.41	10.43	37.38*
Blocks	3	443	1,245	38	18.77	0.33	7.96
Error A	3	649	1,190	1,122	9.53	2.84	4.23
Families	71	166**	176**	77	0.61	0.98	1.10
S x F	71	128**	165**	61	0.73	0.82	1.20
Error B	426	65	100	62	0.61	0.82	1.43

[1]Mean sum of squares followed by an * or ** are statistically significant at the alpha = 0.05 and 0.01 levels, respectively.

dieback on container-grown seedlings for family 386 from Lawrence County, Indiana, averaged 3.6 cm while nursery-grown seedlings of the same family averaged 7.0 cm of net height growth.

Overall, nearly all families showed some first-year dieback for both the nursery-grown and the container-grown seedlings. Nursery-grown seedlings after outplanting were on the average 50.6 cm tall compared to only 46.0 cm after the first growing season. Conversely, container-grown seedlings showed a significantly greater percentage of dieback after the first growing season having averaged 31.3 cm at outplanting and only 23.1 cm after the first growing season. Only family 222 from Huron County, Ohio, outgrew the initial stem dieback for both the nursery-grown and container-grown seedlings and were taller after one growing season than when outplanted.

The variable growth of the nursery-grown seedlings was primarily responsible for the planting stock type x genotype interaction found after the second growing season (Table 2). The second-year growth of both the nursery- and container-grown seedlings for many families was similar. While for approximately one-third of the families, the nursery-grown seedlings showed extensive dieback with little or no dieback on the container-grown seedlings (Table 1). For example, family 146 from Jackson County, Michigan, and family 244 from Mason County, West Virginia, averaged 2 to 4 cm of net height growth for both the nursery-grown and container-grown seedlings, while family 274 from Lawrence County, Indiana, and family 363 from Washington County, Tennessee,continued to show substantial dieback of the nursery-grown seedlings (27.9 and 35.9 cm, respectively) with net height growth for the container-grown seedlings (5.3 and 1.6 cm, respectively).

After the second growing season, many of the nursery-grown seedlings showed additional dieback and were 8.9 cm shorter than after the first growing season. Conversely, the container-grown seedlings were 4.3 cm taller than after the first growing season and had recovered approximately half of the initial dieback. After the second growing season, seedlings from 9 of the 72 families for both the nursery-grown and container-grown planting stock were taller than after the first growing season. Conversely, seedlings from only 8 families showed net dieback for both types of planting stock during the second growing season.

After the third growing season, the interaction between planting stock type and genotype for height growth was no longer present and no differences among families were present (Table 2). Nearly all families showed 4 to 7 cm of net height growth for both types of planting stock. Differences in diameter growth were found only for the planting stock type after the third growing season. Diameter growth for the container-grown seedlings averaged 0.1 mm compared to -0.4 mm for the nursery-grown seedlings. Over two-thirds of the families outplanted as nursery-grown stock showed net negative diameter growth. The negative values occur because of stem dieback on one or more seedlings within these families and subsequent resprouting from the root collar.

Analysis By Seed Collection Zones

Analyses of height growth by seed collection zone and planting stock type again showed a highly significant interaction after the first and second growing seasons. Height growth during the first growing season within each collection zone was extremely variable for planting stock types with no apparent pattern (Table 1). For example, in seed collection zone 6, container-grown and nursery-grown seedlings showed approximately 6 cm of dieback. In contrast, container-grown seedlings from seed collection zone 13 showed extensive dieback (14.5 cm) while nursery-grown seedings from seed collection zone 3 were 3.3 cm taller than when outplanted. The amount of dieback did not appear to follow any geographical pattern related to seed collection zone.

After the second growing season, container-grown seedlings from all seed collection zones consistently showed height growth of 3 to 7 cm (Table 1). In contrast, the amount of dieback on nursery-grown seedlings ranged from 4 to 20 cm across the eleven seed collection zones. Seedlings from the northernmost seed collection zones tended to show the least dieback; however, they also tended to be the shortest when outplanted. A seed collection zone x planting stock type interaction was not found after the third growing season when seedlings from all collection zones averaged 2 to 9 cm of height growth without any apparent geographical pattern.

Results of family mean correlation coefficients showed that increased root fibrosity of nursery-grown seedlings was positively correlated with outplanting basal diameter, first-year height growth, and third-year survival (Table 3). Root fibrosity of container-grown seedlings was not determined and the lack of any correlation between nursery-grown seedling fibrosity and container-grown seedling characteristics of the same family suggests that small changes in root fibrosity on container-grown seedlings are not as important as the well-developed fibrous root system itself.

The lack of any correlation between root fibrosity of nursery-grown seedlings and container-grown seedling growth may also mean that the growth patterns and morphology of seedlings from the same family can be quite different when grown under forcing conditions in a greenhouse. The latter conclusion is supported by the fact that basal diameter of the container-grown seedlings was not correlated with the basal diameter of the nursery-grown seedlings ($r = 0.066$). The outplanting height of the nursery-grown seedlings was correlated with that of the container-grown seedlings; however, the correlation coefficient was relatively low ($r = 0.401$).

DISCUSSION

Survival after three growing seasons in this provenance/progeny test has been exceptional and is substantially better than in an adjacent planting methods study using nursery-grown and container-grown seedlings (Van Sambeek et al. 1987). Survival rates for the nursery-grown planting stock in the adjacent planting after three growing seasons was less than 70% compared to 96% in the present study. We attribute the lower survival in the adjacent planting to the somewhat poorer internal drainage. Survival of container-grown stock after three growing seasons averaged around 95% in both the provenance/progeny and the adjacent planting.

Table 3.--Correlation matrix for initial seedling characteristics and outplanting performance of nursery-grown and container-grown seedlings of 72 black walnut families.

Variables	Root fibr. index	Outplanting Basal diameter	Outplanting Stem height	Annual height growth First year	Annual height growth Second year	Annual height growth Third year	Third year survival
	r[1]						
xxxxxxx			FOR NURSERY-GROWN FAMILIES				
Root fibrosity	xxxxxx	0.367**	-0.104	0.350**	0.015	-0.046	0.238*
Basal diameter	-0.087	xxxxxxx	0.273*	0.497**	-0.128	-0.125	0.183
Stem height	0.129	0.454**	xxxxxxx	-0.386**	-0.778**	-0.123	-0.101
First year growth	-0.144	0.053	-0.700**	xxxxxxx	0.221	-0.176	0.443**
Second year growth	0.094	-0.035	-0.332**	0.154	xxxxxxx	-0.056	0.001
Third year growth	0.144	-0.203	-0.123	0.002	0.437**	xxxxxxx	-0.126
Third year survival	0.167	0.193	0.184	-0.005	0.020	0.285*	xxxxxxx
			FOR CONTAINER-GROWN FAMILIES				

[1]Correlation coefficients followed by an * and ** are statistically significant at the alpha = 0.05 and 0.01 levels, respectively.

The outplanting height for the nursery-grown seedlings was not well correlated with their basal diameter (Table 3). This may be a reflection of the wide variation in seedling density present in the nursery beds due to low germination in some families. Likewise, the outplanting height of the container-grown seedlings was not highly correlated with their basal diameter suggesting that the position of the containers on the greenhouse bench may have affected seedling growth rates.

The overall poor height growth of both the nursery-grown and container-grown seedlings was probably in response to inadequate weed control, moisture stress, and competition from the invading grasses. During the first growing season, many of the nursery-grown seedlings, especially the larger seedlings, showed some dieback with 2 to 5 cm of new shoot growth from lateral buds. Over the winter, the stems on many of these seedlings died. Most seedlings resprouted from the root collar which resulted in large net negative height growth for the second growing season. During the latter part of the second growing season and again during January through March of 1983, rainfall was substantially below normal. This was followed by excess moisture on a somewhat poorly drained site during April and May of the 1983 growing season.

The first- and second-year height growths were negatively correlated with the outplanting height for both the nursery-grown and container-grown seedlings (Table 3). Potentially, the taller seedlings were unable to obtain adequate soil moisture and showed repeated dieback until the root-to-shoot ratios become balanced under stressful conditions. First-year height growth of nursery-grown, but not container-grown seedlings, was positively correlated with outplanting basal diameter. Since taproot volume is highly correlated with basal diameter and is not substantially reduced by root pruning, seedlings with large basal diameters may have had more stored reserves available for root and shoot growth during the first year.

Overall, the container-grown seedlings initiated positive height growth sooner than the nursery-grown seedlings. Similar results have also been found for container-grown planting stock by von Althen and Prince (1986) on a good walnut site and Anderson et al. (1983) on a reclaimed minespoil. Earlier height growth results in our provenance/progeny test are consistent with those from the adjacent planting methods study reported earlier (Van Sambeek et al. 1987). As in the planting methods study, container-grown seedlings in this provenance/progeny test overcame dieback during the second growing season, while nursery-grown seedlings did not show net height growth until the third growing season. Repeated annual dieback for 1 to 3 years in response to site or competition is not uncommon and has been reported for several other provenance/progeny tests (Williams et al. 1985). Heritabilities for height growth were not calculated because previous research has shown them to be highly variable until after the fourth growing season (Rink 1984).

The dissipation of the genotype x environment interaction in Atterbury provenance/progeny test for early height growth is not uncommon in black walnut provenance/progeny tests. In two separate studies, Rink et al. (1982) and Williams et al. (1985) found that the interaction between where the nursery seedlings were grown and genotype also dissipated several years after outplanting. Although seed collection zone (provenance) effects were not found, we expect these effects to be evident in later measurements based on results from other black walnut provenance/progeny tests.

The highly significant planting stock type x genotype interaction during the first two growing seasons reinforces the conclusion from other studies that early height growth cannot be used as a predictor of future height growth, at least for nursery-grown seedlings (Clausen 1984, Rink 1984). Whether early height growth can be used as a reliable predictor for future height growth of black walnut established with container-grown planting stock remains to be determined. The poor initial growth of the container-grown stock in this provenance/progeny, however, makes it unlikely that our study will satisfactorily answer the question. The study has shown that planting stock type x genotype interactions can significantly affect the early field performance of black walnut plantings.

LITERATURE CITED

Anderson, C. P., P. E. Pope, W. R. Byrnes, W. R. Caney, and B. M. Bussler. 1983. Hardwood tree establishment in low plant cover on reclaimed mineland. IN: Proc. Better Reclaim. with Trees Conf., Terre Haute, IN. pp. 158-170.

Bey, C. F. 1979. Geographic variation in Juglans nigra in the midwestern United States. Silvae Genet. 28(4):132-135.

Clausen, K. E. 1982. Age-age correlations for black walnut and white ash. IN: Proc. Seventh North Am. Forest Biology Workshop, Lexington, KY. pp. 113-117.

Deneke, F. J., D. T. Funk, and C. Bey. 1987. Preliminary seed collection zones for black walnut. Wal. Coun. Bull. 14(3/4):2-4, 7.

Funk, D. T. 1978. Genetics of black walnut. USDA Forest Service Research Paper WO-10, 13 p.

Rink, G. 1984. Trends in genetic control of juvenile black walnut height growth. For. Sci. 30(3):821-827.

Rink, G., D. T. Funk, R. D. Williams, T. E. Russell, and W. Lemmien. 1982. Provenance more important than nursery environment to survival and growth of black walnut. IN: Proc. Seventh North American Forest Biology Workshop, Lexington, KY. pp. 152-159.

Rink, G. and J. W. Van Sambeek. 1987. Seedling-sapling growth variation in a southern Illinois black walnut provenance/progeny test. IN: Proc. Fifth North Central Tree Improvement Conf., Fargo, ND. pp. 156-162.

Van Sambeek, J. W., R. D. Williams, and J. W. Hanover. 1987. Comparison of planting methods for nursery- and container-grown black walnut seedlings. IN: Proc. Sixth Central Hardwood Forest Conf., Knoxville, TN. pp. 69-70.

von Althen, F. W. and F. A. Prince. 1986. Black walnut (Juglans nigra L.) establishment: six-year survival and growth of containerized and 1+0 seedlings. Tree Planters' Notes 37:11-14.

Williams, R. D., G. Rink, and D. T. Funk. 1985. Planting site and genotype affect black walnut seedling development more than nursery environment. Can. J. For. Res. 15:14-17.

Wood, B. W. and J. W. Hanover. 1981. Accelerating the growth of black walnut seedlings. Tree Planters' Notes 32:35-38.

TEN YEAR REGENERATION OF SOUTHERN APPALACHIAN HARDWOOD CLEARCUTS AFTER CONTROLLING RESIDUAL TREES

Pilar Zaldivar-Garcia and D. Thompson Tew[1]

Abstract: Two upland hardwood stands were clearcut in 1978 and three treatments to control the unmerchantable and/or cull trees were applied. The treatments applied to the residual trees were chainsaw felling, herbicide injection, and a control, where residual trees were left standing. Regeneration was sampled 10 years after the cutting. Variables such as total number of stems, number of free-to-grow stems, and number of free-to-grow commercial species were used to evaluate the effect of the treatments. Statistical analysis showed that hardwood regeneration is promoted by controlling residual trees. Total number of stems, number of free-to-grow stems, and number of free-to-grow commercial species of the large regeneration class (stems ≥4.5 ft height) were significantly increased by the chainsaw and injection treatments. Controlling residuals significantly increased sprouting of all species (including commercial and non-commercial), the number of free-to-grow trees,and the number of commercial species and free-to-grow commercial species with respect to the control treatment. The number of oaks being regenerated was not affected by either treatment. The injection treatment did not result in a significant increase of the seedling component in the regeneration. Differential mortality was observed among the treatments from years five to ten, resulting in the attenuation of treatment differences, especially between the chainsaw and injection treatments. A shift towards early successional species was observed after the harvest, but the specific composition was unaffected by the treatments. Ten years after the clearcut, the chainsaw treatment is recommended as a means of controlling residual trees. This treatment promoted adequate hardwood regeneration, and compared to the injection treatment, is easier to implement, cheaper and aesthetically more pleasing.

INTRODUCTION

Commercial clearcutting results in the removal of all merchantable trees leaving saplings, small poles and cull trees standing. If residual trees are left uncut they may develop into wolf trees and seriously interfere with the regeneration of commercially desirable species (Trimble 1972; Marquis 1981a).

Regeneration guidelines recommend the removal of those residual trees when clearcutting (Kellison et al. 1981, Roach and Gingrich 1968). Controlling residuals can be done in several

---

[1]Condesa de Mencia, 106bis, 9°B. 09005 Burgos Spain, and Research Assistant, Dept. of Forestry, College of Forest Resources, Box 8008, Raleigh NC 27695-8008.

ways. Large culls can be deadened or felled, and the small residuals can be injected or sprayed with chemicals, lopped with saws or axes or reduced by shearing or drum chopping (Beck 1980).

In this study, two methods of controlling residuals were chosen to examine the response of hardwood regeneration: chainsaw felling and herbicide injection. They were compared to a commercial clearcut in which the residuals were left standing. Deadening of the residual trees with herbicide has the intention of promoting the seedling origin component in the new stand as opposed to chainsaw felling of residuals which should favor the stems of stump origin. This paper reports the differences in the quantity and quality of the regeneration among the different methods of controlling residuals ten years following clearcutting.

METHODS

The two study sites (the Robertson and the Willits tracts) are included within the Chestnut Oak Forest region and are located in western North Carolina on lands that belong to Champion International Corporation. The Willits tract is located in Jackson County on a north to northeast aspect with a red oak site index of 80 ft on a 50 year base (good site). The Robertson tract is located on a north to northwest aspect with a red oak site index of 70 ft (average site).

Portions of the forest on the Willits tract were in pasture or cultivation around the turn of the century, while the Robertson tract was always forested but subjected to repeated highgrading. Both stands were experimentally clearcut in the winter to evaluate alternative methods of controlling residuals. The installation of the study was done by Champion International Corporation in cooperation with the North Carolina State University Hardwood Research Cooperative, and followed the study design found in Kellison and Gardner (1977).

At the time of clearcutting, the Willits tract had a merchantable basal area of 69 square feet per acre in 124 trees per acre aged 60 to 80 years. The trees were mainly red maple (*Acer rubrum* L.), yellow-poplar (*Liriodendron tulipifera* L.), cucumber magnolia (*Magnolia acuminata* L.), hickories (*Carya* spp.), white oaks (*Quercus alba* L., *Quercus prinus* L.), sweet birch (*Betula lenta* L.) and red oaks (*Quercus rubra* L., *Quercus coccinea* Muenchh., *Quercus velutina* Lam.). The Robertson tract had 114 merchantable trees per acre aged 75 to 150, and a basal area of 76 square feet per acre. The primary species at the Robertson tract were white and red oaks, hickories and red maple.

Twelve plots of 1.25 acres were established on each site to allow for 4 replications of three treatments in a randomized complete block design. In each plot, four 0.004 ac subplots were established for regeneration subsampling. The treatments applied to control the residual trees were:

1.- Control: all residual trees left standing to represent the typical condition following commercial clearcutting with a diameter limit of 6 inches dbh.

2.- Chainsaw: clearfelling all residual stems bigger than 1-in dbh with chainsaws.

3.- Injection: injecting all residual stems bigger than 1-in dbh with the herbicide TORDON 101[R] using hypo-hatchets[R].

The original subplot centers were permanently marked for regeneration sampling. Effects of the treatments were evaluated five years after the clearcut by Petruncio (1985).

Ten year regeneration was measured during the summer of 1988. Large regeneration or stems ≥ 4.5 ft tall were sampled on enlarged subplots of 0.02 acres having as a center the smaller 0.004 ac subplots. Species, dbh in inches, height in feet and origin were recorded for every stem. Origin was classed as seedling or sprout. In the case of sprouts, only one dominant stem was measured, but total number of stems per clump was recorded. No distinction was made between seedlings and seedling sprouts. In addition, stems were judged whether they were overtopped by competitors or free-to-grow. Trees identified as present prior to the 1978 harvest were not included in the analysis of regeneration. On the basis of fiber and timber values, species were classified as commercial and non commercial. All oaks (*Quercus* spp.), hickories, pines (*Pinus* spp.), maples (*Acer* spp.), yellow-poplar, cucumber magnolia, blackgum (*Nyssa sylvatica* Marsh.), beech (*Fagus grandifolia* Ehrh), sycamore (*Platanus occidentalis* L.), sweet birch, black cherry (*Prunus serotina* Ehrh), white ash (*Fraxinus americana* L.), eastern red cedar (*Juniperus virginiana* L.), yellow buckeye (*Aesculus octandra* Marsh.), hemlock (*Tsuga canadensis* Carr.) and basswood (*Tilia heterophylla* Vent.) were considered commercial. All other species were considered as having non-commercial value.

To analyze treatment effects on regeneration, number of trees, which is considered to be acceptable in stands less than 15 years old (Gingrich, 1967), has been used as a measure of stand density. The statistical analysis was done on the square root transformation of the data to stabilize the variance (Rawlings, 1988). Analysis of variance was used and planned comparisons among the treatments were done at the 10 percent significance level.

RESULTS AND DISCUSSION

At the time of harvest, the control plots had a residual basal area of 30 ft^2 per acre on both of the tracts. Ten years after the clearcut, the residual basal area was 33 ft^2 on the Willits tract and 22 ft^2 on the Robertson tract. From years 5 to 10, residual tree mortality was 32 percent on the Willits tract and 20 percent on the Robertson. Although mortality has been greater on the Willits tract, the surviving residuals have been able to withstand the severe conditions of sudden exposure better than the ones in the Robertson tract. Quality of the residual trees varies and many show signs of crown dieback and epicormic branching. The high rate of residual mortality surpasses what Marquis (1981) reported for the residual trees in the Allegheny hardwoods. This mortality may be due to the fact that these trees were not selected in any way for species or quality. On the injection plots, many of the trees that were herbicided were still standing as dead snags. The herbicide treatment was almost 100 percent effective on the Robertson tract; however, on the Willits tract some trees survived and at year ten accounted for 7 ft^2 of the basal area per acre. Where mortality occurred, injection resulted in total kill of the tree with no subsequent sprouting.

Large regeneration

Besides analyzing the effects of the treatment on the total number of stems of the large regeneration class (stems ≥ 4.5 ft tall), several species groups were also analyzed separately. Free-to-grow stems were analyzed because they have either a dominant or codominant position in the canopy, commercial species and free-to-grow commercial species were analyzed because of their economic importance, and finally oaks were analyzed due to the interest of silviculturists and the public to promote their regeneration in the Southern Appalachians.

On both tracts, there were more stems per acre of the large regeneration class when the residual trees were controlled, either by chainsaw felling or by herbicide injection, than when the residuals were left standing. In general, the chainsaw treatment resulted in more stems per acre than the injection treatment for the two sites (see Tables 1 and 2). The statistical analysis for the Willits tract (Table 1) revealed that when all large regeneration stems were considered together, no significant differences arose among the treatments, but there were significantly more free-to-grow stems in the chainsaw and injection treatments than in the control treatment . The number of stems per acre of commercially desirable species was not affected by the treatments. The injection treatment produced significantly more free-to-grow commercial species with respect to the control treatment. Petruncio (1985) reported a significant increase in the number of seedling origin stems of commercial species on the injection plots compared to the control plots. The ten year results showed that this trend has not persisted over time and that the number of seedling-origin stems was unaffected by the treatments. On the other hand, the proportion of sprout origin stems was significantly increased by the chainsaw and injection treatments compared to the control treatment. This significance was found for the total stem regeneration, free-to-grow stems, commercial species and free-to-grow commercial species.

Oak regeneration was examined separately from the other species because of poor oak regeneration among the treatments, although the injection plots provided a slightly higher number of oaks per acre than the control and chainsaw plots.

On the Robertson tract, stem density of the large regeneration class was lower than on the Willits tract, but the number of free-to-grow stems and the number of free-to-grow commercial species were greater than on the Willits tract (Table 2). Again, this reflects the difference in site quality between the two tracts. Since the Willits tract was able to support a greater stem density, by year ten it had already reached canopy closure. Although, the Robertson tract had fewer stems per acre and canopy closure was not fully reached, the site had more stems per acre that were not overtopped, compared to the Willits tract. Overall, few significant differences were detected, even though there was a tendency for the chainsaw plots to have higher regeneration densities than on the other plots.

Table 1.--Mean density (stems/acre) of large regeneration stems (≥4.5 ft height) on the Willits tract.

	Treatment		
	Control	Chainsaw	Injection
All species[1]			
Total stems[2]	3938	6100	5191
Seedling stems	1494	1803	1562
Sprout stems[3]	800[a]	1563[b]	1338[b]
Free-to-grow stems			
Dominant stems[4]	675[a]	1178[b]	1240[b]
Seedling stems	306	422	519
Sprout stems	369[a]	756[b]	722[b]
Commercial species			
Total stems	2796	3403	3322
Seedling stems	1146	1403	1796
Sprout stems	434[a]	700[b]	697[b]
Commercial species free-to-grow			
Dominant stems	461[a]	684[ab]	824[b]
Seedling stems	265	334	453
Sprout stems	196[a]	350[b]	371[b]
Oaks			
Total stems	678	875	925
Seedling stems	253	431	588
Sprout stems	163	228	188

Means designated with different letters are significantly different at 0.10 significance level
[1]All species include commercial and non-commercial species.
[2]Total stems include all stems per sprout clump plus seedlings.
[3]Sprouts include only one dominant stem per sprout clump.
[4]Dominant stems include one dominant stem per clump plus seedlings.

The control plots had significantly less total numbers of stems per acre than either the chainsaw or the injection plots. This difference was also observed for the number of stems of sprout origin. The number of free-to-grow stems per acre was increased by the chainsaw treatment when compared to the control treatment. The chainsaw treatment also increased the total number of stems of seedling origin, and the number of stems of sprout origin for the

Table 2.--Mean density (stems/acre) of large regeneration stems (≥4.5 ft height) on the Robertson tract.

	Treatment		
	Control	Chainsaw	Injection
All species[1]			
Total stems[2]	3309[a]	6716[c]	4500[b]
Seedling stems	1772[a]	3263[b]	2847[ab]
Sprout stems[3]	422[a]	841[c]	659[b]
Free-to-grow stems			
Dominant stems[4]	869[a]	2019[b]	1247[ab]
Seedling stems	566	1378	806
Sprout stems	303[a]	641[b]	441[ab]
Commercial species			
Total stems	2381	3134	2750
Seedling stems	1328	1834	1500
Sprout stems	269	319	347
Free-to-grow commercial species			
Dominant stems	629	1134	865
Seedling stems	413	884	584
Sprout stems	216[a]	250[ab]	281[b]
Oaks			
Total stems	856	984	1022
Seedling stems	313	438	366
Sprout stems	147	134	175

Means designated with different letters are significantly different at 0.10 significance level
[1]All species include commercial and non-commercial species.
[2]Total stems include all stems per sprout clump plus seedlings.
[3]Sprouts include only one dominant stem per sprout clump.
[4]Dominant stems include one dominant stem per clump plus seedlings.

free-to-grow class in comparison to the control treatments. It is interesting to note that the injection treatment significantly increased the number of sprout origin stems of free-to-grow commercial species with respect to the control treatment. Also the injection treatment did not have any effect on the number of seedling-origin stems present in the ten year regeneration.

The analysis of the five year regeneration (Petruncio,1985) revealed significantly higher quantities of commercial species in the chainsaw treatment than in the control treatment, and

Table 3.--Mean density (stems/acre) of large regeneration stems (≥4.5 ft height) for the Willits tract and the Robertson tract combined.

	Control	Treatment Chainsaw	Injection
All species[1]			
Total stems[2]	3623[a]	6407[c]	4845[b]
Seedling stems	1633[a]	2533[b]	1955[b]
Sprout stems[3]	611[a]	1202[c]	999[b]
Free-to-grow stems			
Dominant stems[4]	772[a]	1599[b]	1243[b]
Seedling stems	436[a]	900[b]	663[b]
Sprout stems	336[a]	699[b]	580[b]
Commercial species			
Total stems	2589	3269	3036
Seedling stems	1236	1619	1648
Sprout stems	352[a]	509[b]	521[b]
Free-to-grow commercial species			
Dominant stems	545[a]	909[b]	844[b]
Seedling stems	339	609	518
Sprout stems	206[a]	300[b]	326[b]
Oaks			
Total stems	767	930	973
Seedling stems	282	434	477
Sprout stems	155	181	181

Means designated with different letters are significantly different at the 0.10 significance level.
[1]All species include commercial and non-commercial species.
[2]Total stems include all stems per sprout clump plus seedlings.
[3]Sprouts include only one dominant stem per sprout clump.
[4]Dominant stems include one dominant stem per clump plus seedlings.

a significant decrease in the number of oaks of large and small regeneration classes on the injection plots with relation to the control plots. None of these differences have persisted.

To determine if the treatments react differently at both locations, a combined analysis of variance of the two study sites was done (Table 3).

The control treatment presented significantly less total number of stems, free-to-grow stems, and free-to-grow stems of commercial species than the chainsaw and injection treatments . The chainsaw and injection treatments significantly increased seedling origin and sprout origin stems of the total large regeneration and free-to-grow regeneration with respect to the control plots. The proportion of sprout origin stems was also significantly increased by the chainsaw and injection treatments in the commercial species, and the free-to-grow commercial species, compared with the control treatment. The lack of difference in number of sprout origin stems of commercial species between chainsaw and injection treatments is probably a result of the treated residual stems being of non-commercial species.

Neither the number of oaks, nor the seedling or sprout components in the oak regeneration was affected by the treatments. As verified by the treatment means analysis for every location, the injection treatment did not promote the seedling component nor did it decrease the number of sprouts present in the regeneration.

Stand composition

Free-to-grow stems have reached a dominant or codominant position in the canopy so they provide insights into the stand composition for the immediate future. Treatment distribution of the most important species coupled with their sprout percentage is shown for both tracts in Tables 4 and 5.

On the Willits tract, four species, red maple, yellow-poplar, sweet birch, and black locust (*Robinia pseudoacacia* L.), accounted for more than 45 percent of the total stocking and together with the non-commercial group dominated the stand (Table 4). Yellow- poplar was the tallest species in every treatment averaging 22 feet in the control and injection plots and 26 feet in the chainsaw plots. Red maple, sweet birch and black locust followed in height respectively, without marked differences among them. Red maple was by far the most prolific sprouter, averaging 10 stems per clump on the control plots, 6 on chainsaw plots and only 3 on the injection plots.

Both Wendel (1975) and Lamson (1976) demonstrated for hardwood stands such as these, where a high proportion of the regeneration is of sprout origin, that usually one sprout per clump will develop into a good quality tree in the new stand. Sweet birch and yellow-poplar were usually the only species that could germinate from seeds and grow fast enough to occupy the canopy. After clearcutting in the Southern Appalachians, black locust often forms dense thickets that can severely reduce growth of other commercial species (Beck and McGee, 1974). This is why black locust was not considered to be a commercial species in this study. Nonetheless, the effect of black locust on the stand was not seen as detrimental. Black locust sprouted from root suckers and was distributed in small clumps of 2 to 3 individuals scattered throughout the plots but did not form dense thickets. In addition, as Boring and Swank (1984) have pointed out, black locust's short life span coupled with its capacity of increasing soil nitrogen through fixation provides conditions which may facilitate forest growth and successional species replacement.

Table 4.--Number of free-to-grow stems per acre and sprout percentage by species and treatment on the Willits tract.

Species	Control treatment		Chainsaw treatment		Injection treatment	
	Stems/ac	Sprout %	Stems/ac	Sprout %	Stems/ac	Sprout %
Red maple	87	93	99	92	147	74
Yellow-poplar	85	48	125	53	159	33
Northern red oak	32	50	78	44	78	28
Red oaks	15	40	32	41	122	39
White oak	38	66	91	52	59	80
Sweet birch	172	9	140	24	66	33
Black locust	81	100	238	100	188	100
Other commercia	134	22	119	55	192	37
Other non-commercial	131	68	256	66	228	71
Total	675	55	1178	64	1240	58

Table 5.--Number of free-to-grow stems per acre and sprout percentage by species and treatment on the Robertson tract.

Species	Control treatment		Chainsaw treatment		Injection treatment	
	Stems/ac	Sprout %	Stems/ac	Sprout %	Stems/ac	Sprout %
Red maple	200	40	362	22	200	42
Yellow-poplar	115	5	294	4	165	4
Red oaks	48	60	134	30	123	46
Chestnut oak	122	54	153	45	144	46
White oak	44	30	47	34	62	45
Dogwood	100	53	463	54	175	59
Other commercial	170	20	161	21	207	23
Other non-commercial	168	13	400	34	171	29
Total	869	35	2019	31	1247	37

Red oaks predominated the oak regeneration. The amount of northern red oak (*Quercus rubra* L.) present in every treatment was much greater than the density reported by McGee and Hooper (1975) in a ten year old clearcut on the Bent Creek Experimental Forest (North Carolina) of higher site quality. The authors found only 10 free-to-grow red oak stems per acre contrasting with what is reported here; 32 stems per acre in the control treatment and 78 stems in the chainsaw and injection treatments. Beck and Hooper (1986), reevaluating the same stand as in the previous study, reported that 10 years later oaks comprised less than 4 percent of the stand's basal area and northern red oak was less than 1 percent. The northern red oak trees present in this study were 4 to 6 feet shorter than yellow-poplar. More than 55 percent of the chainsaw and injection subplots and 37 percent of the control subplots had one or more northern red oak stem present. The uncertainty that remains is whether these red oaks are going to be able to maintain their present position in the canopy. Oliver (1980) thinks that red oaks will eventually out compete the other species and form the dominant canopy. Beck and Hooper (1986) and Loftis (1988) believe that this will not occur on high quality sites in the Southern Appalachian hardwood forests where yellow-poplar is the major competitor. Species included in the non-commercial group, including dogwood (*Cornus florida* L.), sassafras (*Sassafras albidum* (Nutall) Nees), and sourwood (*Oxydendrum arboreum* (l.) DC), are expected to be soon relegated to the understory. These lower stratum species can act as a "trainers" (Ross et al. 1982) and keep the upper stratum trees well pruned (Oliver, 1980).

On the Robertson tract (Table 5) black locust and sweet birch were absent in the dominant strata. The commercially dominant species, red maple, yellow-poplar, white oaks (especially chestnut oak (*Quercus prinus* L.)) and red oaks, comprised 64 percent of the free-to-grow stems in the control plots, 50 percent on chainsaw and 56 percent on the inject plots. Yellow-poplar had outgrown chestnut oak by 6 feet on the control plots. On the other two treatments, chestnut oak was the tallest tree, although it surpassed yellow-poplar and red maple by only 4 to 2 feet. Because the Robertson tract is of lower site quality than the Willits tract, yellow-poplar was not able to compete as aggressively as it had on the Willits tract. When considering all species together, sprouting percentages were generally lower on the Robertson tract than on the Willits tract. Red maple stems of sprout origin made up 74 to 93 percent of the free-to-grow stems on the Willits tract, but on the Robertson never exceeded 42 percent. This may result from older trees being logged on the Robertson tract, which would decrease the sprouting capacity of the stumps (Wendel, 1975).

Of the non-commercial free-to-grow species, dogwood made up more than 37 percent of the stems, but it was 6 to 12 feet shorter than the tallest dominant tree. Other species that comprised the non-commercial group, mainly sassafras, sourwood and Carolina silverbell (*Halesia carolina* L.) were also shorter than the tallest tree. These species will continue to lag behind the overstory and can regulate sprout clump competition from the side, so they will not expand and dominate large areas (Ross et al. 1982).

Stand development

The total number of stems in the large regeneration class, including all stems per clump plus all seedlings, have declined over time for both tracts (Figure 1). From years 5 to 10 both tracts had control plot mortality rates near 30 percent. The chainsaw plots had mortality rates of 44 and 27 percent on the Willits and the Robertson tracts, respectively. The injection plots had less than 10 percent mortality on both tracts. Mortality rates have decreased the

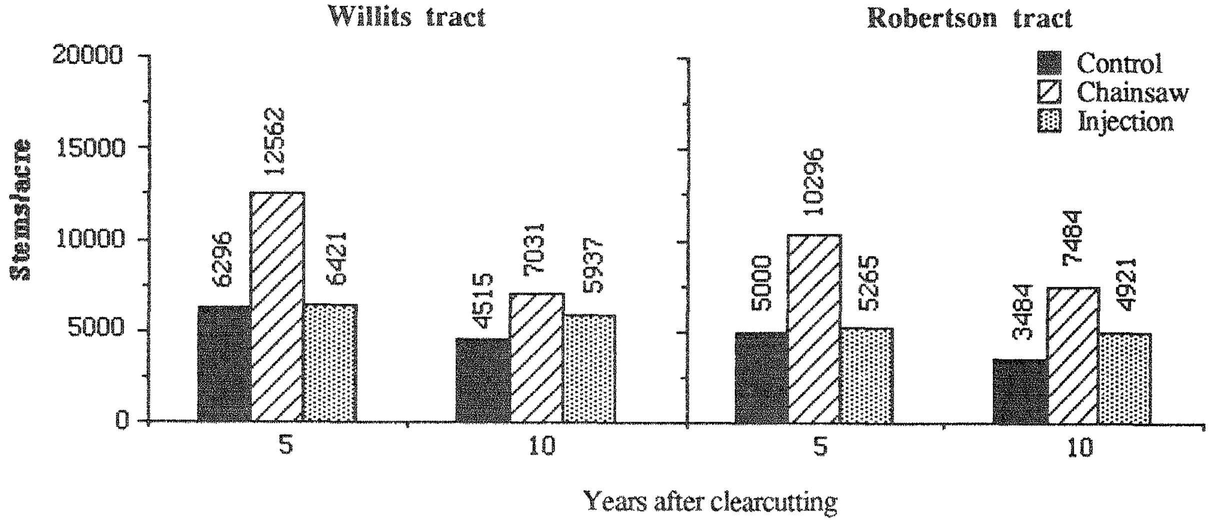

Figure 1. Change in the total number of stems per acre of the large regeneration class (stem≥4.5 ft height) from year 5 to year 10 following clearcutting, by treatment and site.

differences among treatments, especially among the chainsaw and inject treatments. Figure 2 follows sprout-origin (includes only one stem per clump) evolution over the years. Sprout origin stems have decreased by more than 50 percent for every treatment on the Willits and the Robertson tracts with the exception of the inject treatment on the Robertson tract which had only a 22 percent sprout decrease. Again, the differences at year five, particularly among the chainsaw and the injection treatments, have been attenuated to the point that an analysis of variance only detected significant differences among the control and either the chainsaw and injection treatments but not between the chainsaw and the injection treatments (see Tables 1 and 2). A higher reduction of the sprout component was reported by Gammon et al. (1968) for a seven year old hardwood clearcut in southern Michigan where only 22 percent of the sprouts survived. By contrast, seedling origin stems have increased dramatically over time (Figure 3). This increase can be attributed to several factors: seedlings growing over 4.5 feet and moving from the small to the large regeneration class, natural thinning and healing of stems sprouting from stems of small stumps (that at year ten were indistinguishable from true seedlings), and germination of new seedlings that continue to reproduce since the cut (as is the case of yellow-poplar, Minckler and Woerheide, 1965). From years 5 to 10 after clearcutting, the difference in the number of seedling-origin stems between the chainsaw and injection treatments has decreased for both tracts, contrasting to the control treatment where differences have increased in relation to the other two treatments.

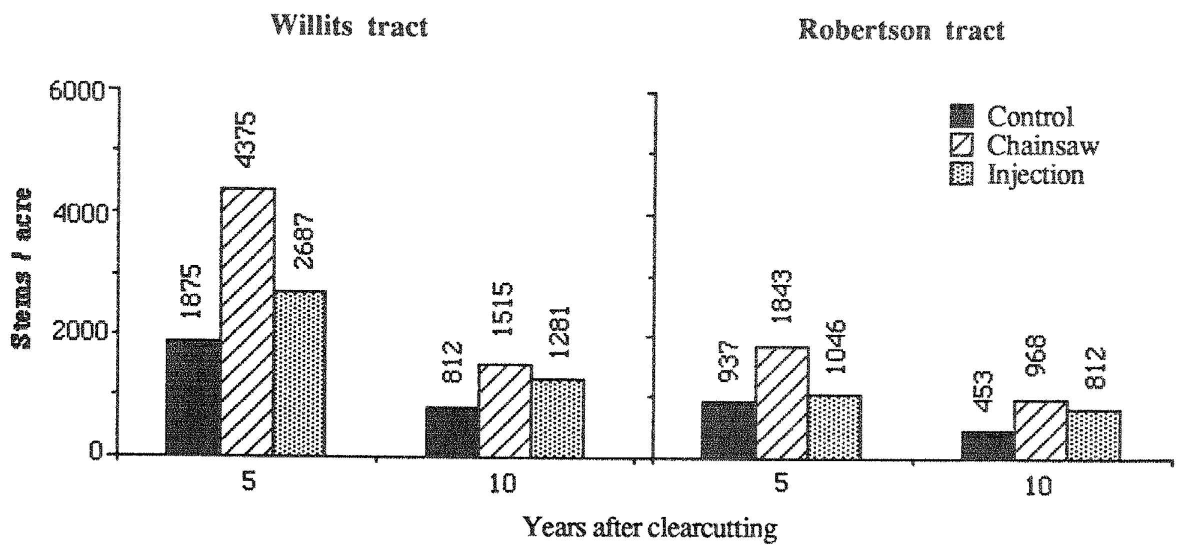

Figure 2. Change in the total number of sprout origin stems per acre (only one stem per clump) of the large regeneration (stems≥4.5 ft height) from year 5 to year 10 following clearcutting, by treatment and site.

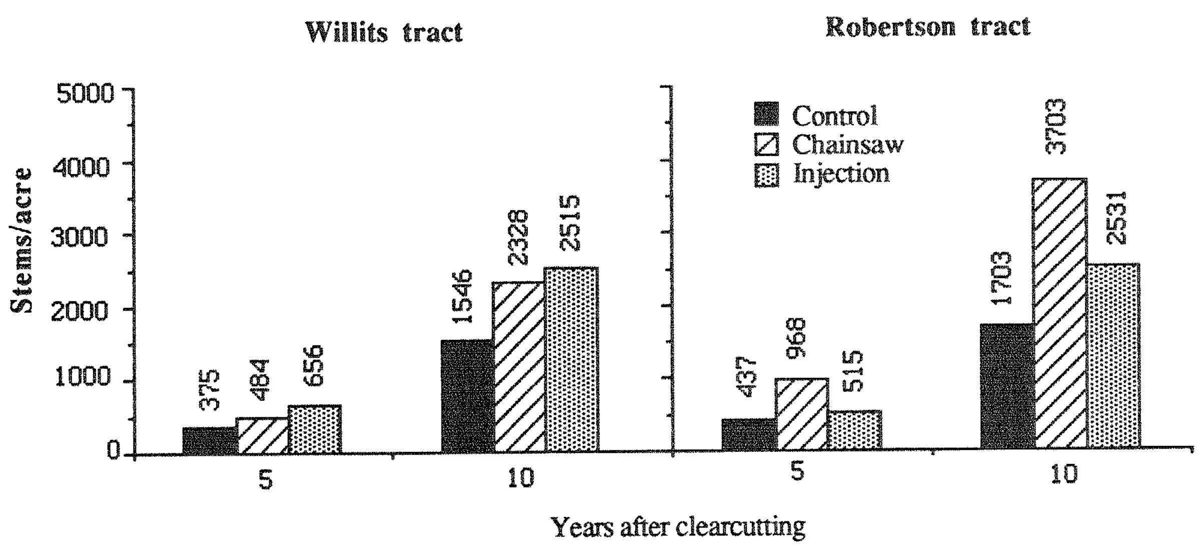

Figure 3. Change in the total number of seeding origin stems per acre of the large regeneration class (stems≥4.5 ft height) form year 5 to year 10 following clearcutting by treatment and site.

SUMMARY

The absence of many of the significant differences that were observed in the evaluation of the study five years ago was a consequence of the differential mortality rates presented by the treatments. This mortality had especially attenuated the differences between the chainsaw and injection treatments. After 10 years, the amount and quality of regeneration promoted by the chainsaw treatment, coupled with its economic and aesthetic advantages over the injection treatment, indicated that chainsaw felling the residuals is the most desirable management option when regenerating hardwood stands of good to average productivity in the Southern Appalachians.

Natural thinning is expected to continue in the years to come as a result of competition, and as Beck and Hooper (1986) reported, the decline may be more rapid in the next five years than what has been observed until now. A follow up of this study is necessary to determine the degree and intensity of the treatments at the end of the rotation.

Besides timber values, other considerations concerning the removal of residuals have to be examined, for example, the economic implications of the treatments. Chainsaw felling the residuals either at the time of harvest or after, is considered to be less expensive than herbicide injection of the residuals (Brenneman, 1988). In regard to aesthetic values, the standing dead trees left by the injection treatment, which persist for at least a decade after logging, can have an adverse impact on the scenic beauty of the stand (Vodak et al. 1985). If wildlife is a matter of concern, leaving chosen residual trees will provide nesting cavities, some mast, and vertical stratification (Smith, 1988). Ultimately, landowner objectives, whether timber oriented or others, will dictate whether and how to remove the residual trees.

LITERATURE CITED

Beck, D.E. 1980. Natural regeneration of southern hardwoods. pp. 132-141. In: R.L. McElwee and N.H. Bell eds. Regenerating the southern forest. 1980 April 17-18; Blacksburg, VA. Tenth Forestry and Wildlife Forum. Blacksburg VA: Virginia Polytechnic Institute and State University

Beck, D.E. and R.M. Hooper. 1986. Development of a southern Appalachian hardwood stand after clearcutting. Southern Journal of Applied Forestry 10: 168-72.

Beck, D.E. and C.E. McGee. 1974. Locust sprouts reduce growth of yellow-poplar seedlings. Res. Note. SE-201. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station, 6 pp.

Boring, L.R. and W.T. Swank. 1984. The role of black locust (Robinia pseudoacacia) in forest succession. Journal of Ecology, 72: 749-766.

Brenneman, B.B. 1988. Westvaco's experience in West Virginia with clearcutting for natural regeneration. pp. 55-60. In: Proceedings of the sixteenth annual hardwood symposium of the hardwood research council: hardwood supply-feast and famine. 1988, May 15-18, Cashiers, North Carolina.

Gammon, A.P., V.J. Rudolph and J.L. Areno. 1968. Regeneration following clearcutting of oak during a seed year. Journal of Forestry, 58: 711-715.

Gingrich, S.F. 1967. Measuring and evaluating stocking and stand density in upland hardwood forest in the central states. Forest Science, 18: 38-53.

Kellison, R.C. and W.E. Gardner. 1977. Generalized working plan for development of southern hardwood stands from natural regeneration. In: Work plans, Hardwood Research Cooperative, NC. State Univ., Raleigh, N.C. (Unpublished).

Kellison, R.C., D.J. Frederick and W.E. Gardner . 1981. A guide for regenerating and managing natural stands of southern hardwoods. N.C. Agricultural Research Service Bull 463. 23 pp.

Lamson, N.I. 1976. Appalachian hardwood stump sprouts are potential sawlog crop trees. Res. Note. NE-229. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 9 pp.

Loftis, D. L. 1988. Regenerating oaks on high-quality sites, an update. pp. 199-209. In: Workshop proceedings: guidelines for regenerating Appalachian hardwood stands. SAF Publ. 88-03. Morgantown, WV: West Virginia University Books.

Marquis, D.A. 1981. Survival, growth and quality of residual trees following clearcutting in Allegheny hardwoods forest. Res. Pap. NE-477. Broomall, PA: U.S. Department of Agriculture Forest Service, Northeastern Forest Experimental Station, 9 pp.

McGee, C.E. and R.M. Hooper. 1975. Regeneration trends 10 years after clearcutting of an Appalachian hardwood stand. Res. Note. SE-227. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station, 3 pp.

Minckler, L.S. and J.D. Woerheide. 1965. Reproduction of hardwoods 10 years after cutting as affected by site and opening size. Journal of Forestry, 63: 103-107.

Oliver, C.D. 1980. Forest development in North America following major disturbances. Forest Ecology and Management, 3: 153-168.

Petruncio, M.D. 1985. Natural regeneration of hardwoods in the Southern Appalachians. M.S. thesis, North Carolina State University, Raleigh, 53 pp.

Rawlings, J.O. 1988. Applied regression analysis. Wadsworth & Brooks, Belmont Ca. 553 pp.

Roach, B.A. and S.F. Gingrich. 1968. Even-aged silviculture for upland central hardwoods. Agric. Handb. 355. Washington, D.C.: U.S. Department of Agriculture, Forest Service. 39 pp.

Ross, M.S., T.L. Sharik ; Smith D.W. 1982. Species and site relationships among oak regeneration types after clearcutting in the Virginia Ridge and Valley. Gen.Tech. Report. SE-024: 151-156. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station.

Smith, R. L. 1988. Is clearcutting hardwoods good for wildlife? pp. 16-33. In: Proceedings of the sixteenth annual hardwood symposium of the hardwood research council. Hardwood supply-feast and famine: 1988, May 15-18, Cashiers, North Carolina.

Trimble, G.R.Jr. 1972. Elimination of scattered residual saplings left after clearcut harvesting of Appalachian hardwoods. Res. Note NE-146. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 4 pp.

Vodak, M.C., P.L. Roberts, J.D. Wellman and G.J. Buhyoff. 1985. Scenic impacts of eastern hardwood management. Forest Science, 31(2): 289-301.

Wendel, G.W. 1975. Stump sprout growth and quality of several Appalachian hardwood species after clearcutting. Res. Pap. NE-329. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 9 pp.

DEVELOPMENT OF REGENERATION FOLLOWING GYPSY MOTH DEFOLIATION OF APPALACHIAN PLATEAU AND RIDGE & VALLEY HARDWOOD STANDS[1,2]

David M. Hix, David E. Fosbroke, Ray R. Hicks, Jr., and Kurt W. Gottschalk[3]

Abstract: The effects of gypsy moth defoliation and subsequent overstory mortality on regeneration were examined in 26 stands in Pennsylvania and Maryland. The Pennsylvania stands were located in the Appalachian Plateau physiographic province, and the Maryland stands were located in the Ridge & Valley province. Pre–defoliation data (1984-1986) were compared with post–defoliation data (1989) from the same 315 six-foot–radius plots. Seedlings of all woody vegetation were counted by species and height class. Separate matched pair t-tests were used to test for differences in pre- and post–defoliation regeneration counts for the most common species in each province. In the Appalachian Plateau, the total numbers of white oak, chestnut oak, and northern red oak decreased while the numbers of less desirable species (red maple, blueberries, raspberries, and greenbriers) increased following defoliation. In the Ridge & Valley, the total number of white oak also decreased; however there was an increase in the number of chestnut oak and northern red oak. The number of less desirable species increased as well, specifically red maple, black cherry, serviceberry, blueberries, and raspberries. In both provinces, there were fewer than 165 oak seedlings per acre in the greater-than-3-foot-height class following defoliation. Therefore, it appears that adequate oak regeneration had not become established in these stands at the time of our study.

INTRODUCTION

The impact of gypsy moth (*Lymantria dispar* L.) defoliation and subsequent overstory mortality on regeneration is of concern to forest managers interested in regenerating oak stands, yet little is known about this impact. It has been reported that some species of

---

[1]Published with the approval of the Director of the West Virginia Agricultural and Forestry Experiment Station as Scientific Article No. 2252. This research was funded by the USDA Forest Service, Northeastern Forest Experiment Station.

[2]The authors thank L. Butler, S. Hollenhorst, H. Wiant, and two anonymous reviewers for their comments on the manuscript, and E. Townsend for statistical consultation.

[3]Assistant Professor of Silviculture, Research Assistant, and Professor of Forest Ecology, respectively, Division of Forestry, West Virginia University, Morgantown, WV 26506 and Research Forester, USDA Forest Service, Northeastern Forest Experiment Station, PO Box 4360, Morgantown, WV 26505.

advance regeneration beneath a defoliated oak canopy (e.g., red maple (*Acer rubrum* L.)) may benefit from the increased light intensity and nutrients in the insect frass (Collins 1961). In a mature oak forest in New Jersey, Ehrenfeld (1980) found that 7-year-old gaps caused by the gypsy moth were dominated by the red maple, American beech (*Fagus grandifolia* Ehrh.), and black birch (*Betula lenta* L.) that had become established in them at or before the time of defoliation. Very little new establishment of plants had occurred; tree reproduction was apparently inhibited or excluded. In 1985, Gansner observed that after 10 years a particular heavily-defoliated oak–hickory stand in northeastern Pennsylvania had very little regeneration of commercial species. Blueberries (*Vaccinium* spp.), witch-hazel (*Hamamelis virginiana* L.), raspberries (*Rubus* spp.), and several species of ferns dominated the understory, along with some tree seedlings that had been heavily browsed by deer. More recently, Allen and Bowersox (1989) found that defoliated oak stands in the Allegheny Mountains and the Ridge & Valley Provinces had understories dominated by red maple, birch, and non–commercial species. Only 4-16% of the stems were northern red oak (*Quercus rubra* L.) or white oak (*Q. alba* L.). In all these studies, the stands were examined several years after defoliation, and their pre–defoliation understory compositions were unknown.

Our study benefitted by the availability of pre–defoliation data, so we were able to compare prior understory compositions with the regeneration that existed after defoliation. The purpose of this paper is to examine the effects of gypsy moth infestation on the development of hardwood stand regeneration in the Appalachian Plateau and Ridge & Valley physiographic provinces.

METHODS

A total of 26 stands were sampled in this study. Seventeen stands were located in the Appalachian Plateau physiographic province in Somerset County, Pennsylvania (Figure 1). These stands are on tracts managed by either the Pennsylvania Game Commission, Westvaco Company, or a private landowner. Topography of the stands ranged from relatively flat, elevated plateaus at 2,250 feet above sea level to rugged, mountainous terrain with many short ridges and steep coves. The average site index for northern red oak was 55 feet (range 32-91). Stands were primarily of pole- and small sawtimber-size and of mixed-oak composition (oaks averaged of 74 percent of the basal area). In general, these stands were moderately defoliated in 1985, severely defoliated in 1986, lightly defoliated in 1987, and virtually undefoliated in 1988 and 1989. The average reduction in percent stocking over the five-year period was 28%. A more detailed description of these Appalachian Plateau stands including their defoliation and mortality histories can be found in Fosbroke and Hicks (1989).

Nine more stands were located in the Ridge & Valley province of western Maryland (Figure 1). All Ridge & Valley stands used in the study are on Green Ridge State Forest in Allegany County, Maryland. Elevations range from 475 to 2,309 feet above sea level. The primary forest type of this area is mixed-oak (oaks averaged 66 percent of the basal area). The average site index was 56 feet (range 34-76). In general, these stands were moderately defoliated in 1985 and 1986. The study stands received little defoliation in 1987, 1988, or

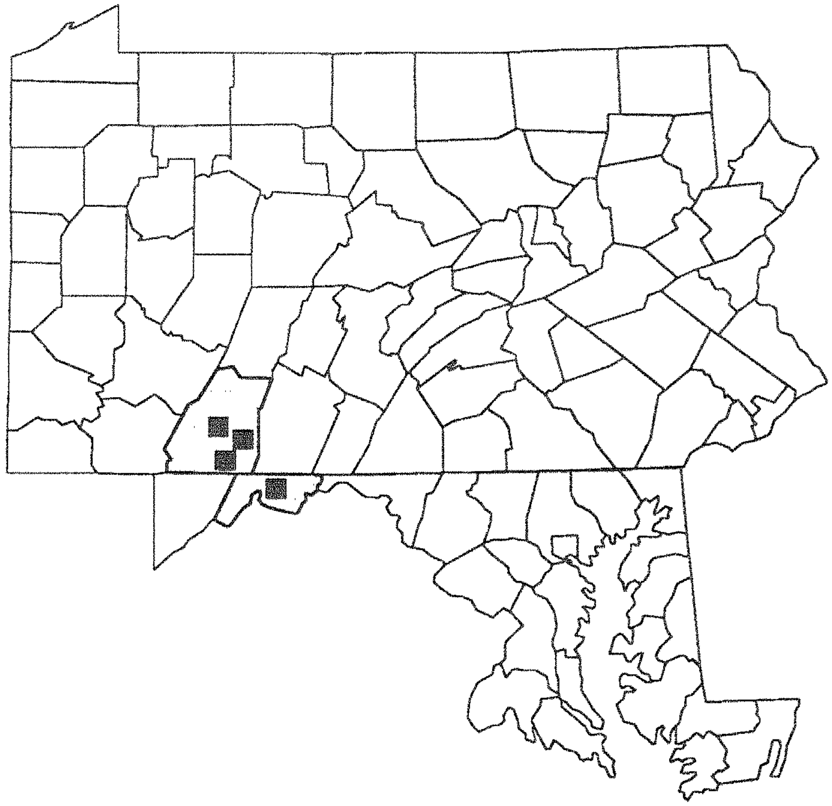

Figure 1. Regeneration plots were located in Pennsylvania and Maryland. The Pennsylvania stands were located in the Appalachian Plateau physiographic province, and the Maryland stands were located in the Ridge and Valley province.

1989. The average reduction in stocking was 14 percent. Though portions of Green Ridge State Forest were defoliated by a looper complex in 1981, none of the stands used in this study were involved in this previous defoliation event. Crow and Hicks (1990) provide a more complete description of the Ridge & Valley stands.

Within each stand, the understory vegetation was surveyed on a series of 6-foot–radius plots. The number of plots per stand ranged from five to thirty. All woody vegetation was tallied by species and height class (< 1.0 ft, 1.0-3.0 ft, and > 3.0 ft but less than 2.9 in. dbh). From 1984 to 1986, 315 plots (194 in PA, 121 in MD) were inventoried prior to gypsy moth defoliation. These same plots were again inventoried following defoliation in 1989.

Analysis of variance indicated that many of the most abundant species differed between physiographic provinces in their response to gypsy moth defoliation and subsequent mortality

(Fosbroke, unpublished data). Therefore, the development of regeneration in each province was analyzed separately.

Since the same plots were measured pre- and post-defoliation, matched pair t-tests were used to determine if there was a significant change in the number of understory stems per acre following gypsy moth defoliation and subsequent tree mortality. A separate test was done for each of the 13 most abundant species (chestnut oak (*Quercus prinus* L.), northern red oak, white oak, red maple, sugar maple (*Acer saccharum* Marsh.), black cherry (*Prunus serotina* Ehrh.), black birch, witch-hazel, downy serviceberry (*Amelanchier arborea* (Michx. f.) Fern.), dogwoods (*Cornus* spp.), blueberries, raspberries, and greenbriers (*Smilax* spp.)). Separate tests were also done for each height class of white oak, northern red oak, chestnut oak, red maple, sugar maple, black cherry, and black birch. Only plots which had a given species either before or following defoliation were included in the test for that species. Therefore, the means reported in Tables 1 and 2 represent the average number of stems per acre for those plots in each province where each species was present. These means do not represent the average number of stems of each species for the entire province.

Each of the species was then placed into one or more of four broad groups for additional testing. The commercial tree species group consisted of red maple, sugar maple, northern red oak, white oak, chestnut oak, black oak (*Quercus velutina* Lam., scarlet oak (*Q. coccinea* Muenchh.), black birch, black cherry, American beech, yellow-poplar (*Liriodendron tulipifera* L., hickories (*Carya* spp.), butternut (*Juglans cinerea* L.), cucumbertree (*Magnolia acuminata* L.), eastern white pine (*Pinus strobus* L.), table-mountain pine (*P. pungens* Lamb.), and eastern hemlock (*Tsuga canadensis* (L.) Carr.). An all oak group contained northern red oak, scarlet oak, black oak, white oak, and chestnut oak. Non-commercial tree species included black locust (*Robinia pseudoacacia* L.), American elm (*Ulmus americana* L.), slippery elm (*U. rubra* Muhl.), sassafras (*Sassafras albidum* (Nutt.) Nees), pin cherry (*Prunus pensylvanica* L.), and black gum (*Nyssa sylvatica* Marsh.). The final group includes shrubs, vines and small trees which are usually restricted to the understory and considered competing vegetation. The species that make up this "all other woody plants" group are blueberries, raspberries, greenbriers, dogwoods, witch-hazel, downy serviceberry, mulberries (*Morus* spp.), crabapples (*Crataegus* spp.), minniebush (*Menziesia pilosa* (Michx.) Juss.), spicebush (*Lindera benzoin* (L.) Blume), eastern redbud (*Cercis canadensis* L.), azaleas (*Azalea* spp.), American chestnut (*Castanea dentata* (Marsh.) Borkh.), honeysuckles (*Lonicera* spp.), currants (*Ribes* spp.), boxelder (*Acer negundo* L.), striped maple (*A. pensylvanicum* L.), grapes (*Vitis* spp.), Virginia creeper (*Parthenocissus quinquefolia* (L.) Planch.), poison ivy (*Toxicodendron radicans* (L.) Kuentze), mountain laurel (*Kalmia latifolia* L.), roses (*Rosa* spp.), devil's walkingstick (*Aralia spinosa* L.), American hornbeam (*Carpinus caroliniana* Walt.), and eastern hophornbeam (*Ostrya virginiana* (Mill.) K. Koch). Comparisons were made for the total number of stems and for each height class for each of these four species groups.

RESULTS

Appalachian Plateau Province

For many tree species, the matched pair t—tests indicated that the average pre-defoliation numbers of stems per acre of various height classes were significantly different from the post-defoliation numbers (Table 1). For instance, prior to defoliation the most common commercial tree species was red maple (5038 stems/acre). The total number of red maple significantly increased ($P < 0.001$) to 10,763 following defoliation. Other commercial tree species that increased in total number following defoliation were black cherry and black birch, while sugar maple decreased (Table 1). However, these changes were not significant ($P > 0.1$). It is interesting to note that the number of stems in the 1-3—foot height class of each of these four species increased following defoliation, although only two of these increases were significant at the 10% level (Table 1). The trend for the all commercial tree species group was similar with significant increases ($P < 0.001$) in all height classes except the greater-than-3-foot class (Table 2).

Numbers of chestnut oak, northern red oak, and white oak of most height classes significant decreased ($P < 0.1$) in numbers after defoliation, with the exception of the 1-3-foot classes (Table 1). But, the increases in the 1—3—foot class for all three major oak species were not significant ($P > 0.2$). However, there was a significant increase ($P < 0.01$) in this height class for the species group that includes all oaks (Table 2). Otherwise, the total number of all oaks and the 0-1—foot class of all oaks significantly decreased ($P < 0.03$) following defoliation. Following defoliation, an average of only 162 oak stems per acre greater than 3 feet tall were present (Table 2).

As a group, the total number of non-commercial tree species increased from 2282 to 2729 stems per acre following defoliation (Table 2). This increase was not significant at the 10% level.

The overall increase in density following defoliation was primarily the result of the large significant increase ($P < 0.001$) in total number of the all other woody plants species group (Table 2). Most of these stems were less than 1 foot tall (Table 2). The two most common species groups following defoliation were blueberries and raspberries, numbering approximately 41,000 and 19,000 stems per acre, respectively (Figure 2). Greenbriers also increased significantly ($P < 0.04$) after defoliation, although by a lesser amount (Figure 2). The total numbers of witch-hazel and serviceberry increased significantly ($P < 0.06$) following defoliation, while there was a significant decrease ($P < 0.02$) in the total number of dogwoods (Figure 2).

Table 1.--Average numbers of stems per acre of the major tree species by height class and paired t-test significance levels for hardwood stands before and after gypsy moth defoliation in the Appalachian Plateau and Ridge & Valley provinces.

Species	Height class (feet)	Appalachian Plateau			Ridge & Valley		
		Pre-	Post-	P > t	Pre-	Post-	P > t
Chestnut oak							
	0-1	1491	856	0.050	3326	6411	0.009
	1-3	372	440	0.412	754	987	0.365
	> 3	122	77	0.032	192	128	0.132
	All	1985	1373	0.086	4172	7526	0.010
Northern red oak							
	0-1	1825	959	0.004	1045	1537	0.049
	1-3	262	363	0.203	175	434	0.004
	> 3	79	41	0.023	8	19	0.181
	All	2166	1363	0.007	1228	1991	0.010
White oak							
	0-1	1981	1438	0.014	4355	3043	0.004
	1-3	420	426	0.959	347	323	0.777
	> 3	144	137	0.742	185	81	0.033
	All	2545	2002	0.056	4888	3447	0.003
Red maple							
	0-1	4143	9807	0.0001	1749	7463	0.001
	1-3	580	756	0.078	821	927	0.340
	> 3	314	199	0.015	271	208	0.219
	All	5038	10763	0.0001	2842	8599	0.001
Sugar maple							
	0-1	1699	1586	0.729	544	1269	0.326
	1-3	498	634	0.235	476	227	0.531
	> 3	709	498	0.076	90	45	0.332
	All	2908	2719	0.583	1110	1540	0.665
Black cherry							
	0-1	1544	1243	0.254	650	5135	0.004
	1-3	385	1010	0.0001	333	465	0.168
	> 3	84	80	0.867	40	160	0.028
	All	2013	2333	0.128	1023	5761	0.002
Black birch							
	0-1	1528	1023	0.250	--[a]	--	--
	1-3	657	1193	0.167	--	--	--
	> 3	549	751	0.320	--	--	--
	All	2734	2968	0.707	--	--	--

[a]In the Ridge & Valley province, black birch was found on only one plot prior to defoliation, and it was not found on any plots following defoliation.

Table 2.--Average numbers of stems per acre of species groups by height class and paired t-test significance levels for hardwood stands before and after gypsy moth defoliation in the Appalachian Plateau and Ridge & Valley provinces.

Species	Height class (feet)	Appalachian Plateau			Ridge & Valley		
		Pre-	Post-	P > t	Pre-	Post-	P > t
All oaks							
	0-1	3195	2163	0.001	6267	6375	0.864
	1-3	594	934	0.001	953	1067	0.427
	> 3	195	162	0.108	222	124	0.011
	All	3984	3259	0.027	7442	7566	0.854
All commercial trees							
	0-1	8138	12052	0.0001	8620	16956	0.0001
	1-3	1703	2909	0.0001	2298	2521	0.319
	> 3	889	782	0.256	729	551	0.028
	All	10730	15743	0.0001	11647	20028	0.0001
All non-commercial trees							
	0-1	1900	1864	0.907	2116	1921	0.441
	1-3	300	751	0.008	997	820	0.071
	> 3	82	114	0.259	172	131	0.431
	All	2282	2729	0.262	3285	2873	0.149
All other woody plants							
	0-1	22405	35700	0.0001	19945	30233	0.0001
	1-3	5688	8988	0.0001	5077	8120	0.0001
	> 3	1503	972	0.0004	2200	1264	0.0001
	All	29595	45660	0.0001	27222	39617	0.0001
All of the above							
	0-1	31519	48577	0.0001	30125	48539	0.0001
	1-3	7566	12277	0.0001	8231	11217	0.0002
	> 3	2456	1811	0.0002	3247	1907	0.0001
	All	41541	62665	0.0001	41603	61663	0.0001

[a]Species groups are defined in the Methods section.

Ridge & Valley Province

As was true in the Appalachian Plateau province, the matched pair t–tests indicated that the average pre-defoliation numbers of stems per acre of various height classes of many tree species were significantly different from the post-defoliation numbers (Table 1). Prior to

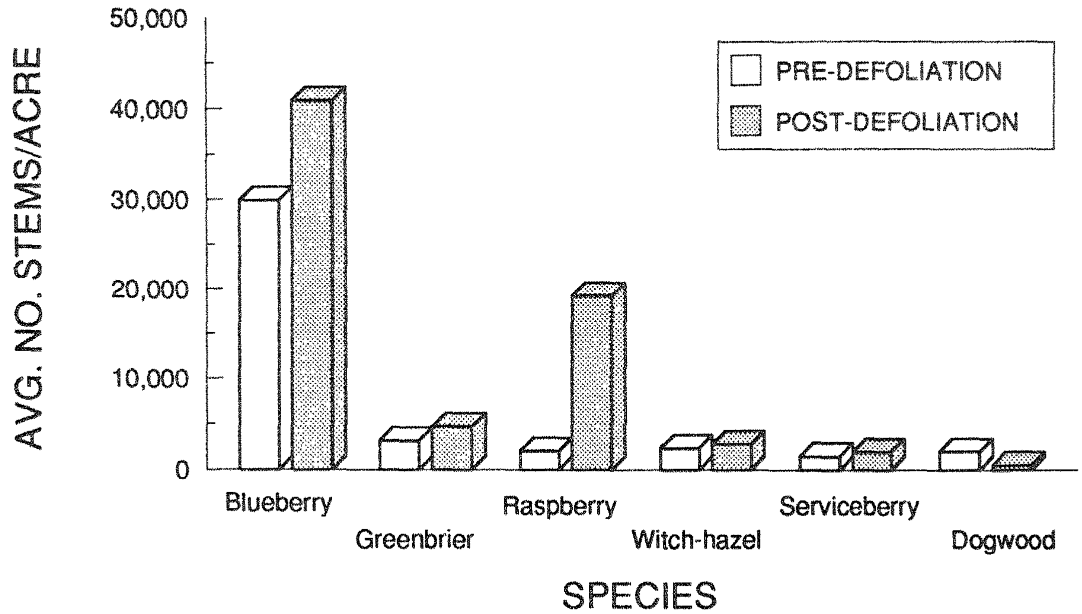

Figure 2. Histograms of the average numbers of stems per acre of the major species of competing vegetation before and after gypsy moth defoliation on the Appalachian Plateau province. All differences between the pre- and post–defoliation numbers were significant at the 10% level.

defoliation, the most common commercial tree species were white oak and chestnut oak (4888 and 4172 stems/acre, respectively). These two oak species reacted differently following defoliation; chestnut oak significantly increased ($P = 0.01$) to 7526 stems per acre while white oak significantly decreased ($P < 0.01$) to 3447 stems per acre. The vast majority of the oak stems were still less than 1 foot tall in 1989. Following defoliation, red maple was again the most common commercial tree species with 8599 stems per acre. Two other commercial tree species that significantly increased ($P < 0.011$) in total number following defoliation were northern red oak and black cherry (Table 1). Sugar maple also increased following defoliation but not significantly ($P > 0.6$). As a group, all commercial tree species approximately doubled with significant increases ($P < 0.001$) in both total number and in the 0-1-foot height class (Table 2). The greater-than-3-foot class significantly decreased ($P < 0.03$) following defoliation.

The only significant change ($P = 0.011$) in any height class for the all oaks species group was a 44% decrease in the greater-than-3-foot class (Table 2). Following defoliation, an average of only 124 oak stems per acre greater than 3 feet tall were present (Table 2).

Each height class of the all non-commercial tree species group decreased following defoliation (Table 2), but only the decrease in the 1-3-foot height class was significant ($P < 0.1$).

Following defoliation, there was a large significant increase ($P < 0.001$) in total number and in the 0-1-foot-height class of the all other woody plants species group (Table 2). Blueberries were still the most common species group following defoliation, with about 16,000 stems per acre present (Figure 3). Raspberries also increased significantly ($P < 0.02$) after defoliation (Figure 3). The total number of serviceberry increased significantly ($P = 0.01$) following defoliation, while there was a significant decrease ($P < 0.001$) in the total number of dogwoods (Figure 3). The total numbers of witch-hazel and greenbriers did not significantly change ($P > 0.7$) after defoliation (Figure 3).

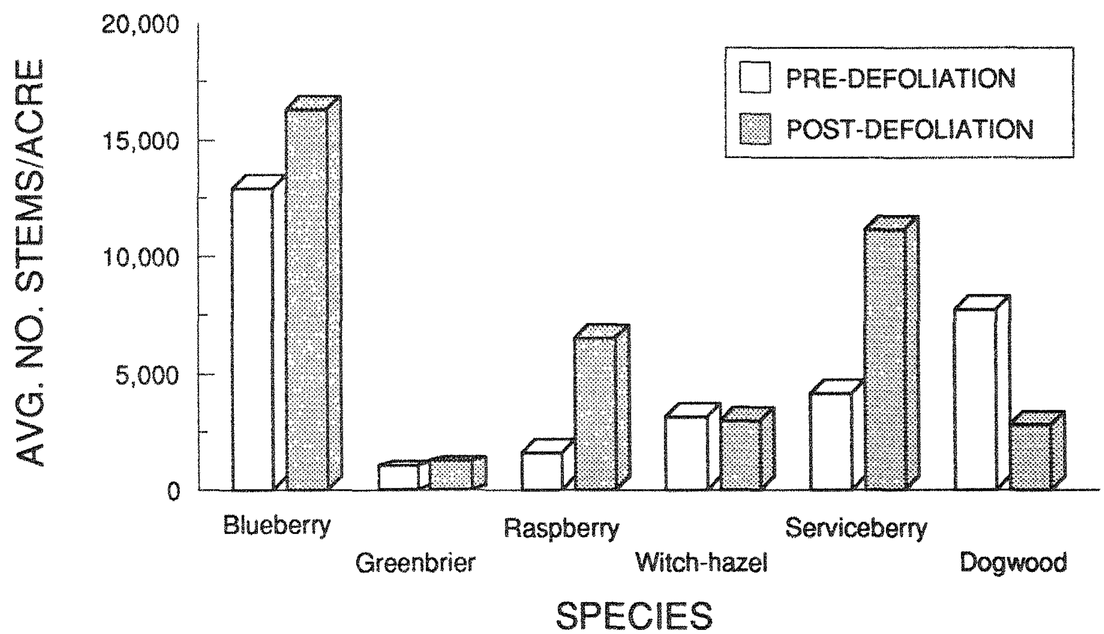

Figure 3. Histograms of the average numbers of stems per acre of the major species of competing vegetation before and after gypsy moth defoliation on the Ridge & Valley province. Differences between the pre- and post–defoliation numbers for blueberry, raspberry, serviceberry, and dogwood were significant at the 10% level.

The total densities, before and after defoliation, were very similar between the two provinces (Table 2). The changes in the number of stems per acre in each height class were also very similar in magnitude and direction (Table 2). All of these changes were highly significant

($P < 0.001$). It is interesting to note that the only decreases were in the greater--than-3--foot-height class.

DISCUSSION

Comparisons of the Results with Other Studies

Tree mortality in gypsy moth-defoliated stands is often patchy, and the result is a mosaic of gaps interspersed within an otherwise continuous forest canopy. Ehrenfeld (1980) studied these kinds of gaps in a New Jersey oak forest seven years following gypsy moth defoliation, and found that their understory composition contrasted sharply with the surrounding "recovered forest". Allen and Bowersox (1989) examined the understories of Pennsylvania stands which had suffered at least a thirty percent volume reduction of the overstory due to gypsy moth-induced mortality. Their regeneration counts were made six to seven years following mortality. They concluded that although commercial tree species were adequately regenerating, lower-value species were still much more common than the oaks. The results from the current study provide additional information about the change in regeneration occurring over a short period of time following defoliation and subsequent overstory mortality. Our data come from stands which experienced a range of defoliation levels and suffered various degrees of tree mortality. In stands where mortality was moderate to severe, trees began dying by the summer of 1986. Therefore, these data represent a point in time 2-3 years following the initiation of tree mortality, and it remains to be seen how the regeneration will develop in these stands in the future.

A lack of an increase in species richness led Ehrenfeld (1980) to suggest that new species are not recruited following gypsy moth-induced tree mortality. Those species which were already present on the site expanded to fill canopy gaps. We also did not find new species establishing 1-3 years following tree mortality. In fact, prior information about the number of stems of a given species prior to defoliation is highly significant in determining the importance of that species in the understory following defoliation (Fosbroke unpublished data).

This paper does not attempt to describe differences in the response of understory vegetation to gypsy moth under varying levels of defoliation, mortality, and site quality. However, it is expected that the higher the level of defoliation and subsequent mortality, the greater the understory response. Results of analysis of variance tests by Fosbroke (unpublished data) indicate that overstory mortality, site index, and physiographic province are all important factors related to the differences between pre- and post-defoliation regeneration.

There seems to be a consensus among forest managers who have seen the effects of gypsy moth defoliation that the understories in defoliated stands are dominated by low-value species. Results from earlier studies suggest that this is usually the case (Ehrenfeld 1980, Allen and Bowersox 1989). The results of our study also indicate a profusion of seedlings of species which will either not become a part of the overstory or will be of low value. In ours and other studies, red maple, black birch, blueberries, and raspberries were often the species which increased the most following defoliation. There is also an increase in the total density from about 42,000 to 62,000 stems per acre in both provinces, as a result of the additional light, nutrients, and moisture reaching the forest floor.

In both provinces, the dogwood genus reacted differently than the other major species of competing vegetation. There were significant decreases in the total numbers of dogwoods (primarily *Cornus florida* L.) following defoliation. This is in contrast to the stands studied by Ehrenfeld (1980) where flowering dogwood became the most common species in the understory following defoliation. Perhaps this difference between the two studies is due to site or geographical factors, or it may indicate the increased incidence of the lethal disease dogwood anthracnose (Hibben and Daughtrey 1988) in forests of the study area.

Differences in Regeneration Between Provinces

Though we did not test for differences in regeneration counts between provinces as did Allen and Bowersox (1989), some comparisons can be made between their results and ours. The Allegheny Mountains are a subregion of the Appalachian Plateau physiographic province. Plots located there by Allen and Bowersox were geographically near our study areas. In comparing post-defoliation densities between the two studies, both studies show a similar trend for red maple with respect to province: the Ridge & Valley province had fewer red maples per acre in the understory following defoliation than the Appalachian Plateau province. However, Allen and Bowersox found roughly twice as many red maple per acre in both provinces as we did. In contrast, Allen and Bowersox found less than half as many birch stems per acre in the understories of Allegheny Mountain stands following defoliation than we did on the Appalachian Plateau. The greatest difference between the two post-defoliation regeneration tallies was that we found virtually no birch in the Ridge & Valley province compared with the 7,986 stems per acre found by Allen and Bowersox. Differences are expected between the means of any two regeneration studies of this type due to random variability and to the unequal amounts of time following defoliation. Regardless, in both studies red maple and black birch appear to be thriving in post-defoliation understories and are likely to become serious competitors with the more valuable species for growing space, nutrients, moisture, and light.

Other forms of ground vegetation besides tree seedlings are very important restrictors of the future establishment and growth of desirable regeneration. Allen and Bowersox (1989) found ferns and blueberries to be the most common species in the ground cover. Ferns occupied an average of 38 percent of the ground in the Allegheny Mountains and 6 percent in the Ridge & Valley province. Blueberries covered 14 percent of the Allegheny Mountain sites and 21 percent of the plots in the Ridge & Valley province. Although we did not determine the coverage of ferns, there is no doubt that blueberries and raspberries are also important competitors in the stands we studied. In the Appalachian Plateau province, we found approximately 35,000 stems per acre of these two species prior to defoliation. Following defoliation, the number increased to 65,000. In the Ridge & Valley province, both the pre- and the post-defoliation number of these species were somewhat lower, 15,000 and 23,000 stems per acre, respectively.

Future Development of Oak Stands in These Provinces

The problem of regenerating oaks on good sites is a serious concern of forest managers throughout most of the eastern United States (Lorimer 1989). In this study, white oaks of all height classes consistently declined in numbers following gypsy moth defoliation. Northern red oak and chestnut oak also decreased in total number in the Appalachian Plateau province, but increased in the Ridge & Valley province. The majority of the increases were in numbers of stems less than 3 feet tall. Interestingly, there was even an increase in the numbers of these two oak species in the 1-3—foot height class for the Appalachian Plateau province. Oak seedlings were generally more common in the Ridge & Valley province than in the Appalachian Plateau province. Allen and Bowersox (1989) also found more oak seedlings in the Ridge & Valley.

It appears that the existing advance regeneration of oaks is responding to defoliation by increasing in height. However, only about 125-165 oak stems per acre are presently tall enough (greater than 3 feet) to have a chance of successfully competing with other faster-growing species like black cherry, black birch, and red maple. It is unknown precisely how many oak seedlings (and of what size) should be established in a stand before it is regenerated. Sander *et al.* (1976) concluded that at least 430 seedlings at least 4.5 feet tall would be needed to ensure a pole-size stand containing 30% oaks. In our stands, regeneration is currently insufficient to meet this criterion. The oak component in future stands will depend to a great degree on how many of the small oak seedlings (0-1 foot tall) survive and grow. Because of the influx of competing vegetation (e.g., red maple, blueberries, and raspberries), we speculate there may be a reduced oak component of gypsy moth—defoliated stands in the future. Because of this shift in composition and the increased species diversity of stands, the future impact of the gypsy moth may be diminished in these provinces.

LITERATURE CITED

Allen, D., and T. Bowersox. 1989. Regeneration in oak stands following gypsy moth defoliations. pp. 67-73 *In* Seventh Central Hardwood Forest Conf. Proc. *Edited by* G. Rink and C. A. Budelsky. Carbondale, IL. USDA For. Serv. Gen. Tech. Rep. NC—132.

Collins, S. 1961. Benefits to understory from canopy defoliation by gypsy moth larvae. Ecology 42: 836-838.

Crow, G. R., and R. R. Hicks, Jr. 1990. Predicting mortality following spring insect defoliation. For. Sci. 36: 831-841.

Ehrenfeld, J. G. 1980. Understory response to canopy gaps of varying size in a mature oak forest. Bull Torrey Bot. Club 107: 29-41.

Fosbroke, D. E., and R. R. Hicks, Jr. 1989. Tree mortality following gypsy moth defoliation in southwestern Pennsylvania. pp. 74-80 *In* Seventh Central Hardwood Forest Conf. Proc. *Edited by* G. Rink and C. A. Budelsky. Carbondale, Il. USDA For. Serv. Gen. Tech. Rep. NC-132.

Gansner, D. A. 1985. Ten years after gypsy moth and still no regeneration. Pennsylvania Forests 75: 6,12.

Hibben, C. R., and M. L. Daughtrey. 1988. Dogwood anthracnose in the northeastern United States. Plant Disease 72:199--203.

Lorimer, C. G. 1989. The oak regeneration problem: new evidence on causes and possible solutions. Dept. of For. Forest Resource Analysis No. 8. Univ. Wisconsin, Madison. 31 pp.

Sander, I. L., P. S. Johnson, and R. F. Watt. 1976. A guide for evaluating the adequacy of oak advance reproduction. USDA For. Serv. Gen. Tech. Rep. NC-23. 7 pp.